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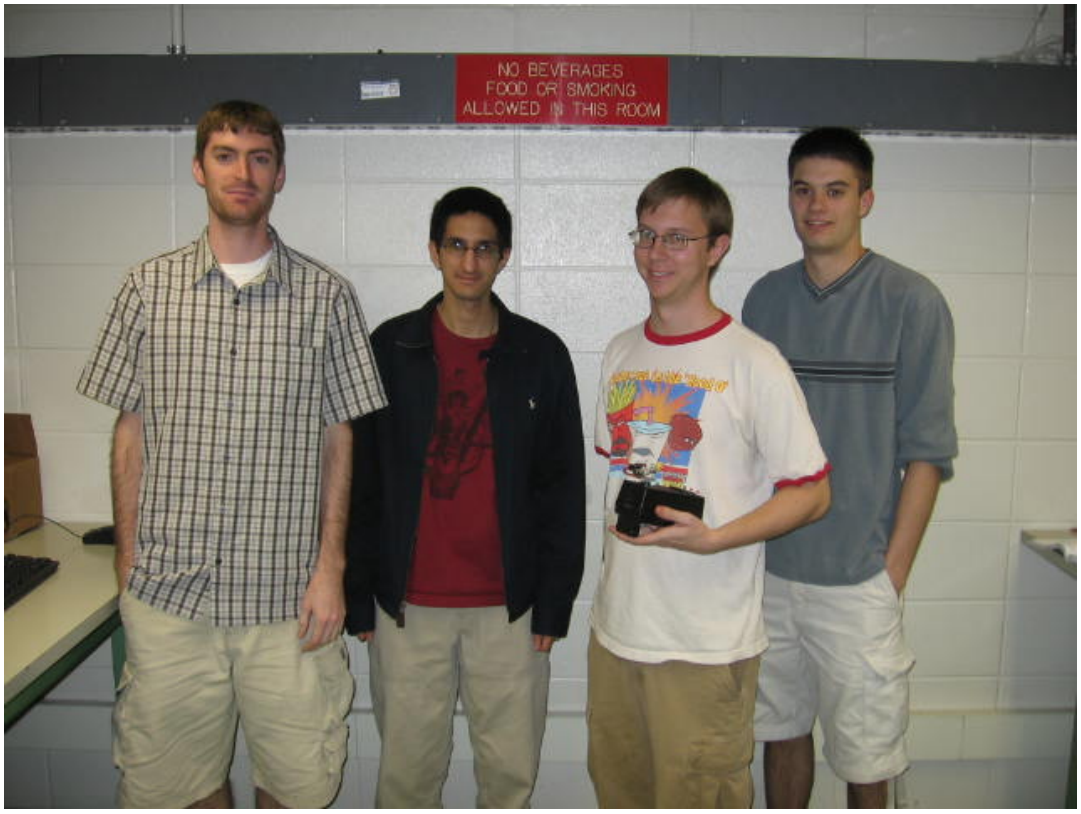
Spring 2006



Team Code Name: Motion Tracking System **Team ID:** 9

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REPORT EVALUATION

Component/Criterion	Score	Multiplier	Points
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Comments:

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Abstract

The project is a motion tracking system. It uses a CMOS image sensor to take images, a Freescale microcontroller to process the images, and servo motors to aim a laser pointer at the center of the widest moving object in view. The project also includes a real time clock which is used to timestamp motion events. Users interact with the system through push buttons, potentiometers, and an LCD screen.

1.0 Project Overview and Block Diagram

The Motion Tracking Camera Platform design project provides a system for capturing image data from a CMOS image sensor and performing a simple, and therefore relatively time efficient, image processing algorithm to detect and track motion real-time within the field of view. The module automatically translates the motion location into a target point within the object bounds, and provides servo control signals that cause properly calibrated motors to aim a pan/tilt platform toward that target point. For the purpose of proof of concept, a laser pointer is activated atop the platform to verify correct target locations, but the system provides a backbone for many applications such as security devices, basic sight emulation robotics, or automatic video recording devices. In addition to the autonomous operation of the motion tracking system, a user interface is provided in the form of pushbuttons and an LCD module to display useful information such as the timestamps of significant events.

Figure 1.1 – Completed Project Photograph

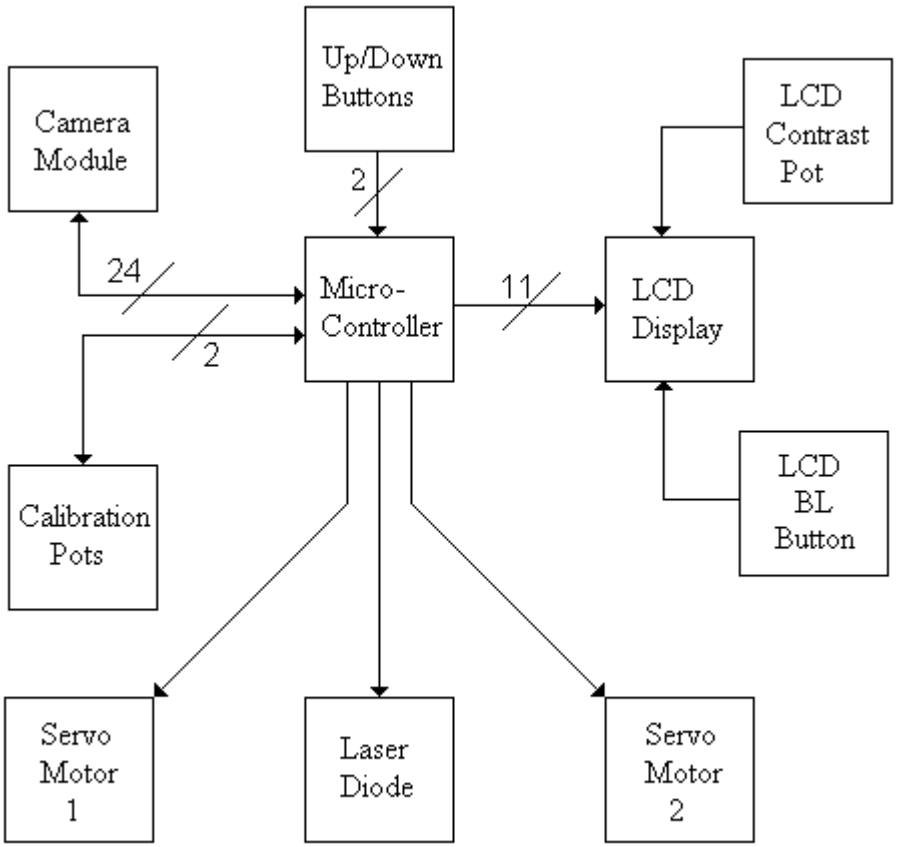

Figure 1.2 – Project Block Diagram

2.0 Team Success Criteria and Fulfillment

Project Specific Success Criteria:

- An ability to analyze successive stored images for changes/movement in field-of-view.
- An ability to calibrate laser-aiming platform relative to camera field-of-view.
- An ability to aim laser at a torso 10 feet away.
- An ability to timestamp and log motion events.
- An ability to configure/control system operation and view event logs via pushbuttons/LCD.

All five project specific success criteria were successfully demonstrated. The difference algorithm is able to determine whether movement occurred. The calibration routine successfully determines values to calculate where to aim. The find center algorithm successfully determines the proper PWM duty cycle to point at a torso ten feet away. The real time clock runs

successfully and events are properly time stamped. Users are able to successfully interact with the device using the pushbuttons, potentiometers, and LCD.

3.0 Constraint Analysis and Component Selection

3.1 Computation Requirements

The processor must be able to determine the location of a moving object and focus the laser pointer on its center in real time. To do this, the processor first acquires a reference image to use from the camera and stores it in the microcontroller's memory. From then on, images are captured at a fixed interval and sent to the microcontroller, which runs a simple difference filter on the new image and the reference frame. If a difference is seen (meaning an object has come into view that is not in the reference frame), the center of the detected object is determined, and the microcontroller outputs PWM signals to two servo motors (used to control tilt and pan) that point the laser at the moving object.

3.2 Interface Requirements

The microcontroller interfaces to the camera, the LCD, two push buttons, the on/off switch, the laser pointer, and the two motors. The camera requires 20 pins of I/O in total, 16 for image data and 4 for control signals. The LCD interface requires 11 pins of I/O, 3 for control signals, 8 for data values. The two push buttons each need one pin of I/O. The laser pointer needs one pin, and each PWM output also needs one output pin. In total, the microcontroller will need 36 I/O pins.

3.3 On-Chip Peripheral Requirements

There are a few on-chip peripheral requirements for the design. An I^2C bus interface is needed to set register values on the camera. The TIM system is needed to keep a real time clock running, which is used to keep timestamps of motion events. Two timer channels are required to generate the necessary PWM signals at 50 Hz each.

3.4 Off-Chip Peripheral Requirements

The off-chip peripherals required are an LCD interface, push buttons for scrolling through the LCD interface, enabling/disabling the LCD backlight, an on/off switch, a laser pointer, and two servo motors. The LCD interface is used to display the timestamp data. Three push buttons are used: two push buttons for scrolling through the LCD interface, and one push button for enabling the LCD backlight. A simple two position switch is used to turn the device on or off. A standard red laser diode is used to project the laser beam on the moving object. The two servo motors are used to tilt and pan the laser pointer.

3.5 Component Selection Rationale

The design has two major component choices. The first choice was to determine which camera to use. Multiple cameras were examined and researched, and the decision was narrowed down to either the Omnivision OV6120 [1] or the Kodak KAC-9630 [2]. Both cameras use the I^2C bus for setup. The Kodak camera has a resolution of 128 x 101 pixels, and the OV6120 has a resolution of 352 x 292. Both cameras are monochrome. Both cameras also had a downside. The Kodak KAC-9630 is meant for more high speed applications, able to capture 580 frames a second, making it a very expensive ($270 plus $100 for a matching lens). The problem with the OV6120 is that there are no American vendors for the part. Instead, we decided to go with the OV6620, which differs from the OV6120 in only one aspect: the 6120 is monochrome, and the 6620 is color (in fact, they are so similar, they share a data sheet). The OV6620 is sold for $43.65 along with a lens.

The second choice was microcontroller selection. The microcontroller needed to have all of the required peripherals as well as plenty of memory and be fast enough to meet the real time constraints. The newer 16-bit 9S12 and 9S12x series microcontrollers from Freescale have most of the on-chip peripherals needed (the older microcontrollers did not have onboard I^2C controllers) and run fast (25 MHz). Two microcontrollers were investigated, the MC9S12DP512 [3] and the MC9S12XDP512 [4]. Table 3.1 shows a comparison between the two devices.

Microcontroller	MC9S12XDP512	MC9S12DP512
Internal RAM	32,768 Bytes	12,288 Bytes
Flash Memory	524,288 Bytes	512,000 Bytes
Serial Interfaces	CAN, IIC, SCI, SPI	CAN, IIC, J1850, SCI, SPI
Timers	8	8
PWM Channels	8	8
PWM Bits	8	8
I/O Pins	91	91
Additional Peripherals	Periodic Interrupt Timer	Addressable External Memory

Table 3.1: Comparison between two Freescale microcontrollers

The MC9S12DP512 was chosen because the one reference image could fit in its memory with enough room to spare for difference data and other variables. Also, it would cost a lot more to be able to program the MC9S12XDP512 as the cheapest programming suite available cost $600. Therefore the group chose to work with the MC9S12DP512.

4.0 Patent Liability Analysis

4.1 Results of Patent and Product Search

After searching the USPTO webpage [5] several patents were discovered that need to be analyzed. The patents were found by searching issued patents on the USPTO webpage for the phrase “motion tracking”. The search returned 525 patents, however most of them were not relevant to the project. Most of the patents were rejected from analysis because they did not use a camera to detect motion. Therefore the project can perform the same functionality but do so in a substantially different way than the issued patent. There are five patents that need to be analyzed because they are similar to the project and the patents are still in effect.

United States Patent 6,819,778 [6]

This patent is for a “Method and system for tracking a fast moving object”. This patent is for a system that will move a camera to follow a moving object. It does this by storing two

video frames into two memories and comparing the two frames. If motion is detected the camera zooms in on the object and tracks it until it is no longer visible. More advanced calculations are preformed to determine how far the camera needs to pan to still track the object. The patented device does not look for known shapes in the video frame it only detects motion.

United States Patent 5,243,418 [7]

This is a patent for "Display monitoring system for detecting and tracking an intruder in a monitor area". The patented product stores a background image in memory as a reference. Differences are found between new images and the background image. They "binarize" the differences by checking the difference to a stored threshold value. This is done to make the patented product "resistant to environmental variations".

4.2 Analysis of Patent Liability

The project has limited potential to literally infringe on the above patents. The process of storing a reference frame and comparing it to a new frame is the only aspect that is literally the same as some of the existing patents. However, this is not significant since so many patents were issued that have the same frame comparison method of detecting motion. Also, the method is never mentioned as a claim in any patent by itself. This comparison is also obvious to anyone skilled in the art so it should not be patentable. The patents differed literally from the project because when there was movement involved in the patent the image sensor was being moved. There is a greater chance for the design to infringe on patents under the doctrine of equivalents. The USPTO describes the Doctrine of Equivalents as a way of answering the question, "Does the accused product or process contain elements identical or equivalent to each claimed element of the patented invention?" [8] Since moving the image sensor and moving a laser are very similar they could be argued to be equivalent. The movement is only specified as sending a control signal to a motor. The motor could be connected to anything and be controlled the same way. The project moves the laser by modifying the duty cycle of a PWM output. The PWM output is connected to a servo motor that controls either the pan or tilt of the laser. Lastly, tracking motion could be argued to be the most significant part of a device that moves the camera to follow motion.

4.3 Action Recommended

The project group feels that there is not any infringement because by not moving the image sensor the processing is much simpler. There is no correction for the different image that will be received after moving the image sensor in the project. This simplicity represents a substantial change in the implementation. Also, by not moving the camera the functionality of the project is different from the patented devices. The project can not view a moving object for as long as the patented devices because of its fixed field of view. There is still some potential for infringement because the differences between the project and the patented products could be argued obvious to someone trained in the art. The project group recommends only moving the laser to avoid infringing on existing patents. If the camera were to move with the laser there would be much more of a chance for literal infringement.

5.0 Reliability and Safety Analysis

To better understand the overall reliability of the entire design without an exhaustive analysis of each individual component, a focused approach is used to examine a few of the critical components which are most likely to fail. Chosen based on complexity and operating temperature, four devices are selected for this analysis and their failure rates will be quantified by procedures developed by the United States Department of Defense and detailed in the MIL-HDBK-217F [9]. The selected components are summarized in Table 5.1 below.

Part Number	Description	Part Failure Rate (λ_p)	MTTF
MC9S12DP512	Microcontroller, 16-bit, 112 pin SMT	5.376 Failures/ 10^6 Hours	186011.9048 Hours (21.234 years)
LTC1174-5	Step Down DC-DC Converter, 8 pin DIP	5.868 Failures/ 10^6 Hours	170415.8146 Hours (19.454 years)
OV6620	CMOS Image Sensor, 16-bit, 48 pin SMT	4.671 Failures/ 10^6 Hours	214086.9193 Hours (24.439 years)
PC 1202-A	24 Character LCD Display Controller, 8-bit, 80 pin SMT	2.92 Failures/ 10^6 Hours	342465.7534 Hours (39.094 years)

Table 5.1 – Selected Reliability Analysis Components

Each of the parts listed in Table 5.1 fall under the Microcircuits category (section 5.0) of the military handbook. The following sections in the document outline the values and associated assumptions used to compute the failure rate for the given device using the following formula:

$$\lambda_p = (C_1 * \pi_T + C_2 * \pi_E) * \pi_Q * \pi_L \text{ Failures}/10^6 \text{ Hours}$$

where:

- λ_p is the part failure rate,
- C_1 is the die complexity failure rate,
- π_T is the temperature factor,
- C_2 is the package failure rate,
- π_E is the environmental factor,
- π_Q is the quality factor, and
- π_L is the learning factor.

Mean time to failure (MTTF) is then calculated as the inverse of the failure rate, or $\mathbf{10^6 / \lambda_p}$. Calculation specifics, including parameters and justifications, for each component analyzed are included in Appendix G.

The microcontroller [10] is an obvious weak point of the design due to its complexity and importance to the circuit. As one of the components that is setting the upper bound on the lifecycle of the system, it is being considered for the reliability analysis. Most of the parameters are clearly defined by the given information about the chip including junction temperature, pin count, package type, and production phase. The only assumption made with the MC9S12DP512 is that it falls into the non-hermetic packaging category, which produces a higher approximation for failure than the other options. It is also worth noting that the maximum junction temperature, T_j, is used in the analysis to provide the 'worst-case' failure rate, which is the case for all components considered. As seen in the resulting failure rate values, the microcontroller poses a moderately significant threat to the reliability of the system, even more so considering that a failure with the microcontroller will result in complete loss of system functionality. In the event of such a failure, the entire device would likely have to be replaced.

The linear regulator [11] is arguably the most critical component on the board as it provides power to all components and has the highest failure rate of any device in the design. A critical

assumption was made with the LTC1174-5, that it contains 1 to 100 transistors, an approximation made based on the function block diagram provided in the datasheet. Similar to the microcontroller, it is also assumed non-hermetic and a worst-case approximation is made with the junction temperature. The results show that the linear regulator is slightly less reliable than the microcontroller, but enough so that it is the most likely component to fail. A typical failure would likely cause the device to have to be replaced, however the DIP package makes it easier to diagnose and repair if possible.

A significant subsystem involved in the motion tracking project is the camera module [12]. Instead of analyzing the entire module, just the image sensor chip is considered. The sensor is assumed to be similar to a 16-bit microcontroller with a conservative assumption of junction temperature, matching the specifications for the microcontroller itself. This analysis is closely related to the microcontroller, with the exception of the number of pins, so the reliability issues are similar. Different from the microcontroller, however, is that a failure of the image sensor can be fixed by simply replacing the camera module PCB. This result of having a modular design is an attractive feature of the system in the case of device failure.

The LCD panel and associate driver circuit [13] is not necessarily a 'mission critical' subsystem, but is deserving of reliability analysis due to the similarity to other devices considered. The segment driver, a Samsung S6A0069X, is essentially an 8-bit microcontroller and the junction temperature assumption is made similar to the camera module. Since this controller is relatively simple compared to the rest of the components analyzed it has the lowest failure rate, with an MTTF just short of 40 years. As with the image sensor, the modular design allows an LCD failure to be corrected by replacing the inexpensive LCD module.

A simple analysis of the four major components provides good insight into the reliability of the entire system. Under assumptions that over exaggerate actual operating conditions, the results summarized in Table 5.1 indicate an approximate failure rate for the entire system. The most critical component in terms of shortest failure rate is the linear regulator, which is unfortunate due to the difficulty of repair, but expected nonetheless. Close behind is the microcontroller, which is also a difficult component to service. The gaps between failure rates continuously increase with the image sensor being next, followed by the LCD controller. These values are acceptable due to the general ease of replacement, and in reality are even lower when actual junction temperatures and loading conditions are taken into account.

In order to facilitate the failure mode, effects, and criticality analysis (FMECA), the schematic is divided into several blocks by function. This breakdown is summarized in Table G.1, included in Appendix G. Two criticality levels are appropriate for the design, referred to as 'high' and 'low.' A high criticality is defined as any failure in which physical injury is a possible result. This includes, but is not limited to, the possibility of fire, explosions, or excessive heating. A low criticality is defined as any failure that does not have the potential to cause physical harm, but one which would render at least part of the system unusable and cause customer dissatisfaction. In a final system design, failure probabilities would be set to $\lambda < 10^{-9}$ for a high criticality level, and $\lambda < 10^{-5}$ for a low criticality level, standard accepted industry values. It is important to note that the motion tracking camera system can be potentially more harmful if it is specified for use in a security setting. Although this use is not recommended under the current design, the criticality level is defined as "low/high" for these cases. The completed FEMCA table is found in Appendix G [14].

6.0 Ethical and Environmental Impact Analysis

6.1 Ethical Impact Analysis

When considering the ethical impact of this project, there are many things that need to be taken into consideration involving the application of the system. Depending upon the application, there could be potential for harm to users or to non-users who happen to be nearby. If this project is used in a toy robot, the concern of the laser pointer comes into play. How dangerous is it to have a laser pointer shine into someone's eye? The risk of damage from a laser pointer has to be reduced by placing a piece of filtered glass in front of it. This reduces the power of the laser pointer significantly and makes it safe for everyday use as long as the eye is not exposed to it over extended periods of time. A warning label placed on the product would be beneficial to inform the user of the possible hazards of extended exposure to lasers.

Another concern involved with this project is the inability to differentiate targets. Since the camera is black and white and fairly low resolution, it would be nearly impossible to create an algorithm for target differentiation unless the only difference was the color being black or white. If this project is used as a sentry turret type of system, there is nothing stopping it from shooting

or aiming at friendly targets since it has no way of telling the difference between hostile and enemy targets. This could potentially cause harm to the user or nearby people who are unaware of the system. This must be very well explained in the user documentation as well as include a warning label near the power on button to inform the user of the potential hazards. Also, to allow for the safe passage of friendly targets through the area covered by the system, a "laser off" switch has been implemented. This allows the user to disable the laser pointer at the flip of a switch to allow motion to pass by without any harmful results to the moving object.

As with any electronic devices there is always the possibility of fire or electric shock to the user if the device is handled incorrectly or if a malfunction occurs, especially with devices containing batteries, as batteries can explode when exposed to fire. Warning labels should be placed on the package informing the user of such possible harm and the user manual should also warn of these dangers. Extra sealant is used on the PCB to make sure there are no exposed connections. The packaging completely encloses the system, so there should be no access to the PCB or any components, therefore making it very difficult to touch anything carrying current and reducing the risk of shock. The battery pack will need to be accessible, so the battery casing contains the highest risk of shock within the system unless it is used incorrectly or disassembled. The power on/off switch is included to allow the user to shut off power at any time.

Another ethical consideration is to make sure you are not selling a product that is expected to fail or malfunction. Extremely thorough testing must be conducted before approving this project for manufacture, sale, or use. Especially with the potential harmful effects to the user and nearby people if a malfunction occurs, there needs to be virtually no possibility of malfunction before releasing this product. If it is used in a toy robot, a malfunction could cause extended exposure to a laser pointer causing damage to the eyes or possibly even blindness. If it is used in a sentry turret system, it could inadvertently injure friendly targets or fail to correctly aim at hostile targets, thus allowing them to pass through the detected area without any negative effects. If it is used in a security system, it could fail to track a target and could lead to hostile targets breaking into a secure compound.

6.2 Environmental Impact Analysis

Manufacture

This project contains multiple parts that project possible environmental hazards during manufacture. The PCB is one of the main concerns as there are many environmentally harmful processes used in PCB fabrication. Cleaning and surface preparation of the PCB uses multiple types of acids, halogens, and alkaline solutions and produces a number of harmful byproducts. During the metal plating process, byproducts such as acids, stannic oxide, palladium, and chelating agents are created. During the pattern printing and masking process, chlorinated hydrocarbons and alkali are some of the byproducts and during etching ammonia, chromium, and acids are among the harmful byproducts. [15] There are various leftover metals as well that are too small to be reused or recycled so they are generally thrown out. There are multiple steps that could be taken to reduce the harmful waste created from fabricated PCBs, but realistically there is no way to eliminate it. Some of these steps include making a more compact PCB design which would ultimately reduce the overall size and weight of the PCB, therefore having less waste created. Another way would be to use possibly more expensive, but more environmentally friendly methods of PCB manufacturing that do not contain such harmful chemicals.

Normal Use

During normal use of this product, there are very few environmental concerns associated with it. One of the main concerns is the fact that it contains lead. Lead solder is used to connect parts to the PCB, many of the headers contain lead, the PCB itself contains lead, and the microcontroller used in this project contains lead. Lead is considered to be fairly dangerous to be exposed to and many countries and companies are putting forth a large effort to reduce or eliminate the existence of lead in available products. Even short term exposure to lead can lead to vomiting, diarrhea, convulsions, coma, or even death. Anemia, constipation, and kidney problems are also concerns involved with extended exposure to lead. Pregnant women and young children are especially susceptible to the harmful effects of lead, which can cause stillbirths or miscarriages [16]. If this product were to be widely manufactured, more advanced precautionary steps would need to be taken to ensure as little lead as possible is used to create it. Lead-free solder is available and could be used, as well as an RoHS compliant version of the

microcontroller, although it is more expensive. Some RoHS compliant headers are available, although in some cases headers were used only for convenience and may not even be necessary in a finished product.

Another possible health concern during normal use is possible exposure to mercury. Almost all products in the United States have made their best effort to rid themselves of mercury due to the dangerous side effects of exposure, but some parts may still contain trace amounts. Harmful effects of mercury exposure can include damage to the nervous, digestive, and respiratory systems [17]. Many batteries used to contain mercury, but most companies, like Duracell, have removed all traces of mercury from their batteries and manufacturing processes [18].

Disposal and Recycling

Disposal of many electronic products is considered dangerous or harmful to the environment and this product is no exception. It contains many hazardous substances and should not be disposed of in the normal ways. Although it is not extremely beneficial or profitable to recycle printed circuit boards, the extracted materials and boards can be reused and save some money as well as protect the environment. The user documentation should include information notifying the user that the product should not be disposed of in a normal way, but it is difficult to convince people not to do so. PCB manufacturing companies need to provide easy ways to recycle for users and the product documentation should include methods of recycling or contact information regarding recycling.

The batteries used in this project could also pose an environmental hazard depending upon what kind of batteries the user decides to use. Most alkaline batteries are safe to be disposed of normally, but you should refer to the battery manufacturer to be sure before disposing of them. Battery manufacturers such as Duracell [18] have made an extra effort to make their batteries environmentally safe. Most rechargeable batteries are not considered to be environmentally safe and you should contact the battery manufacturer for details on how to correctly dispose of such batteries. Alkaline batteries are recommended for this product, so the disposal of batteries should not be a problematic issue.

7.0 Packaging Design Considerations

7.l Commercial Product Packaging

The two products selected for analysis are the Creative WebCam Live! Motion and the x10 MultiView. These two products share features in common with the project without directly implementing it.

Creative WebCam Live! Motion

First, the Creative WebCam Live! Motion [24] is a webcam that has the ability to pan, tilt and zoom in order to automatically follow a moving body. If there are multiple moving bodies it will zoom out to try and keep both bodies in the video feed. The camera is capable of moving 200 degrees horizontal and 105 degrees vertical. It has a USB 2.0 interface to a PC that allows it to capture 30 frames per second of 640x480 resolution video. The camera also has a shutter button on the top that will trigger it to take a picture. The camera has a stand with a fold out leg that can either sit on any flat surface, such as a CRT monitor or the leg can be folded down to straddle a LCD monitor. A very nice feature of the camera is its very wide viewing range is accomplished with a very small motor mount at the base of the camera. A major downside to the packaging is the inclusion of a USB interface. The length of the cable determines what can be captured by the camera, whereas if the camera were wireless then much more could be captured. There is not much the project is able to copy or adapt from this product. The project's camera is going to be stationary and only the laser pointer is going to move. Comparing the two designs is difficult because the designs were created with different goals.

x10 MultiView

The x10 MultiView [25] is a system of PC peripherals and software that allow up to four video cameras to interface to a computer. A picture of the total system from the x10 webpage is listed as Figure 2. The computer program can simultaneously monitor live video feeds from all four cameras. The system also features a mode very similar to the project where the camera will go into a sleep like state until it detects motion. Once the camera is alerted it begins saving pictures to the PC and recording a timestamps on each picture. The cameras the system interfaces to are either wireless XCam2 or WideEye cameras. Both cameras are wireless video cameras with a

1/3” CMOS image sensor. They can be powered from an AC adapter or by batteries. The only difference between the cameras is the WideEye has a much larger viewable range. A good part of the system's packaging is the use of four cameras. This greatly increases the area that can be protected by the system. A major downside to the system requires the use of a computer to store the images. This is not a standalone security solution. Also, the cameras need to be purchased separately from the MultiView package. This is confusing on their web page which degrades the system's ease of use. This system also is a pure surveillance system, there is no way to stop an actual intruder.

7.2 Project Packaging Specifications

The PCB is housed in a Serpac-153 hobby box and there are several holes on the top and front of the box. The box's dimensions are 5.630”x3.250”x2.510”. This gives enough room to comfortably hold the PCB, camera and LCD screen. There is a hole cut out the front of the box for the camera. The pan motor is mounted to the top of the box and there is a hole cut out of the top for the LCD screen. The text is displayed so you can read it when facing the rear of the device. There are two buttons to scroll through the saved timestamps. An additional button on the top will turn on the backlight for the LCD. There is a bracket, for the tilt motor, that is connected to the pan motor. The tilt motor is attached to the bracket and the laser is attached to the tilt motor. Moving the pan motor moves the bracket, the tilt motor and the laser. By moving the two motors the laser can point at the movement. The laser was placed directly above the camera so that it will be easier to aim the laser at the target. The socket for the AC power adapter is recessed into the box on the bottom left. There is a power switch on the bottom right of the box. Along the side there are three recessed potentiometers. They are used for calibration and for the LCD contrast. They are turned with a small straight blade screwdriver only. The whole box is held up at an angle by a spacer attached to the bottom of the box. This allows the camera to see directly in front of the box.

7.3 PCB Footprint Layout

The microcontroller is a MC9S12DP512, which comes in a 112 pin LQFP package. The CMOS image sensor comes in a 48 pin LCC package. There is a module available for the image sensor

that outputs to a 32 pin header placed on the PCB. The project uses the module because of the ability to rapidly prototype with the camera. The PCB is 2.5" wide and 3.3" long.

8.0 Schematic Design Considerations

8.1 Microcontroller

The microcontroller that will be used in this project is the MC9S12DP512 [4]. It is in a 112-pin LQFP package. 112 pins may be more than necessary, but a large amount of pins are needed to connect to all of the peripherals and off chip components. The camera module [26] that will be used in the project requires a 32 pin header, 25 of which will go to the microcontroller. Most of these will require generic I/O ports, but most notably two of them are reserved for I^2C data and clock signals. The pixel clock, vertical sync, and horizontal reference signals will be wired to interrupt pins so that the chip will know exactly when to read in each pixel as it is sent. Pixel data and configuration settings can be sent to the microcontroller from any I/O pin. The LCD module [27] chosen for this project has a 16 pin header, 12 of which go to the microcontroller. All 12 of these pins can be generic I/O, but for simplicity the 8 data pins will be routed to an eight bit data register that is mapped directly to eight data pins. The two motors [28] that pan and tilt the laser pointer platform both require a PWM input from the microcontroller. Unfortunately, the servo motors require a 50 Hz pulse wave and the PWM channels can not go that slow when the chip is clocked at 25 MHz. A custom PWM wave has to be created using the ECT/TIM channels. ECT channel 7 controls the frequency of the pulses on the other channels. Channel 3 and 5 are used for the two pulses going to the two servo motors and each channel controls the duration of the pulse. These channels are controlled by a 16 bit value representing pulse duration. The laser pointer will also require a signal from one of the microcontroller's output pins to tell it when to turn on/off. Two potentiometers will be used for calibration of the motors and will each use an ATD converter. Two buttons will be used for scrolling between the events list (and also used at start up to set the clock) and each require an input pin. A spare eight pin header will be connected to one of the registers that are mapped to pins for easy data output in case the project requires an expansion of microcontroller outputs or inputs. The programming header will need connections to the BKGD pin and the RESET pin. The microcontroller will also need a PLL filter and a clock signal from a resonator. These require specific pin assignments that occupy nearly half of the lower side of the microcontroller.

For the microcontroller itself, the model was chosen due to meeting all of the above necessities as well as having a large amount of RAM. The I^2C capabilities, PWM channels, and ability to map pins to the interrupt vector were the largest constraints, as well as being able to run fast enough to read in pixel data from the camera and manipulate it accordingly with time to spare. The PLL circuit was documented in the data sheet and recommended three capacitors of values 4.7nF, 470pF, and 100nF as well as a 100k ohm resistor. Bypass capacitor values were suggested between 100 and 220 nF for the power supplies to the microcontroller.

When the microcontroller reads in pixel data from the camera, it runs it through an algorithm to find difference data between the current frame and a reference frame. After a full frame has been captured, it runs that frame through a special routine to find objects within the difference data, which essentially represent motion in the field of view of the camera. It will then calculate values to output to the ECT registers that control where the servo motors aim based on where the motion was detected within the image.

8.2 Clock Oscillator/Resonator

The 25MHz ceramic resonator [29] chosen for this microcontroller is called the AWSCR, from Abracon. It comes as a three pin device with a crystal connected to two internal capacitors that lead to one pin labeled ground. The other two pins are for input and output to the crystal, output being the 25MHz clock signal being used by the microcontroller. The manufacturer recommends tying the input and output together through a 1M ohm resistor and 25MHz is the manufacturer's maximum recommended clocking speed for this specific microcontroller.

8.3 Camera Module

The camera module, the C3088 [26] which utilizes an Omni Vision 6620 color camera chip, will be connected to a 32 pin header on the PCB that is setup as 16 pins by 2 pins. 25 of these 32 pins will be connected to the microcontroller; of the other seven, four will be connected to ground and two to five volt power. The last pin is for analog video output and will mainly be used for testing; however a wire will be run to the outside of the box so that it is accessible to watch the video feed. Of the 25 pins going to the microcontroller, 16 are reserved for data, one for reset, one for power down mode, two for I^2C, one for odd field flag, one for horizontal reference output, one for vertical sync output, one for pixel clock output, and one for optional

external clock input. This project will not make use of the odd field flag or the external clock input. The 16 pins for data allow the transfer of two bytes at a time, even though each pixel takes four bytes to represent. The Y (luminance) byte will be the only one used in this project, so eight of the 16 data pins will not be used unless the camera is operating in black and white mode. The VSYNC, HREF, and PCLK signals are extremely important for telling the microcontroller when images, rows, and individual pixels are being sent, which is why they have all been mapped to interrupt pins. The camera module itself already contains its own internal pull up resistors, oscillator for the clock signal, and bypass capacitors.

8.4 LCD Display Module

The LCD module, the PC-1202-A [27], will connect to the PCB through a 16 pin header (two rows of 8 pins). Eleven of these pins will be wired directly to the microcontroller, two of them will be ground, and one of them will be power. The last two pins will be connected to other components. One will go to a potentiometer output that will control the LCD contrast adjust pin and the other pin will be connected to a push button that will connect to power when pressed and connect to ground when depressed. This signal will control the LCD backlighting so that it will be easier to see, if necessary, but not use up power when unnecessary. Of the eleven pins connected to the microcontroller, eight of these pins are for data so that one byte can be sent at a time. One pin will be for selecting read or write, one pin for enabling the device, and one pin for register select when reading data from the LCD. This project will not be reading from the LCD module, so the register select will not be used and the read/write pin will always be set to write. The LCD is used mainly for communicating with the user in setup and calibration, but can also be used to view timestamps of motion events any time during normal operation.

8.5 Motors

The motors, GWS NARO STDs [28], will each have a small three pin header connected to the PCB. One of the pins will be for ground, one for five volt power, and one for the PWM output from the microcontroller. This PWM output will be the control signal that determines the position of the motor based on the duty cycle. The motors will be physically attached to platforms that move the laser pointer, although the motors will have no electrical connection to the laser pointer.

8.6 Laser Pointer and Laser On/Off Switch

Two of the pins coming out of the Button/Laser header will go towards the laser pointer. One is a ground signal and one is the output from the microcontroller that will turn on when movement is detected and it is attempting to point at a target. There will be a SPST switch between the header and the laser pointer that will allow a user to manually disable the laser pointer if desired.

8.7 Up/Down Push Buttons

The two push buttons used for scrolling through the event cycle and for setting the clock will each be attached to a two pin header, which is attached to ground and the microcontroller. The pins on the microcontroller that it attaches to will be ones that are able to be used as active low interrupt pins so that the microcontroller does not need to constantly poll the pushbuttons, it will just be sent an interrupt when they are pressed. Pressing a button will pass the ground signal to the microcontroller input which will be viewed as a short and when depressed they will leave the microcontroller input as an open circuit.

8.8 Calibration Potentiometers

There will be two 10k potentiometers [30] directly on the bottom of the PCB. They will be accessible, although not easily, so that they can be changed to calibrate the motor alignment, but not accidentally moved around to mess it up. They will each be attached to power and ground as well as a microcontroller input to an ATD converter. The value put out by the potentiometer will be used in the motor aiming algorithms to calibrate, align, and correctly aim the laser pointer at the target.

8.9 Power Circuit

The power circuit connects the battery power and power from a wall wart through two Shottky Diodes [31] to ensure current flowing in the right direction. The battery power will come from a pack of 4 AA batteries. Immediately after the diodes, there will be a SPST switch that controls whether or not power will actually be connected to the board or not. Following the switch will be a MIC29150 power regulator [32] to ensure that no more than five volts reaches

the circuit components. A bypass capacitor connects the real five volt power coming out of the regulator to ground. In order for the MIC29150 to output five volts, the input voltage must be at least six volts from the data sheet formula of ($V_{out} < V_{in}$ -1). Therefore, rechargeable AA batteries can not be used (unless five batteries are used instead of four) due to the lower voltage of 1.2V. Regular alkaline 1.5V AA batteries will be used. Much of the component selection was based on a five volt power requirement in order to greatly simplify the power circuit and power constraints by only needing one voltage source level.

8.10 Programming Header

The 9S12 series chips have a simple way of connecting to a background debug module [33], using only the BKGD and RESET pins from the microcontroller and power and ground signals. Both the BKGD and RESET pins need to be connected to power through a 10k ohm resistor.

8.11 Expansion Headers and Expansion PLD

Incase it is needed in the future, an expansion PLD port will be placed on the board in a 20 pin DIP package with each side attached to a ten pin header for easy access. It will not be connected to anything else on the board and must be manually wired when/if it is needed.

9.0 PCB Layout Design Considerations

When viewing the PCB layout as a top down design process, many general considerations are presented, including standard good design practices and project specific issues. These general points can be broken into physical considerations and electrical considerations, and further into hard constraints which must be followed and soft constraints which are preferred, but not required. The major physical hard constraints for this design are component sizes. The microcontroller is a 112-pin, 22 mm^2 LQFP package [34] which allow a 12 mil trace width to the pins. Headers for all external connections have pins spaced at .1” and are arranged as 2x17 for the camera module, 2x8 for the LCD, 1x3 for all potentiometers and servo connections, 1x6 total for the pushbuttons and laser enable, and several 1x2 headers for the various remaining connections. In total, these headers make up a large percentage of the component area on the

PCB and must be arranged for efficient use of space and ease of routing. The camera header is a unique hard constraint in that it must be close to the appropriate edge of the board to avoid the use of long ribbon connector, which would be hazardous to critical clock data. The final physical dimension worth noting is the power circuit, since the voltage regulator is a TO-220 package [32] which is relatively large compared to the type 1206 surface mount components used elsewhere.

Physical soft constraints include the location of components on the board, with the exception of the camera header which is now considered fixed. In an effort to reduce interference, the voltage regulation circuit should be kept separate from the digital sections and close to the power input and battery location in the back of the package. The LCD header should be placed near the location of the LCD panel, which is the next component inward from the power circuit. With this arrangement, it makes logical sense to position the microcontroller between the camera and LCD headers, near the center of the board. Orientation of the microcontroller is determined by the most critical traces on the PCB, the camera's PCLK and HREF clocking signals. Wanting these signals to be input to interrupts, and considering the I/O requirements (detailed below) for each peripheral, the optimal microcontroller orientation is easily determined. With these major components placed, all other connectors are placed to minimize distance to their respective microcontroller pin connections. With intelligent selection of these connections, this leaves a large area open for the sensitive oscillator circuit and bypass capacitors. The final component layout shows the successful implementation of the above considerations with a final board size of 2.5" wide by 3.3" long.

The general electrical considerations are made up of manufacture circuit requirements, considered hard constraints, and noise reduction practices, considered soft constraints. Freescale provides a suggested PCB layout for all power, ground, oscillator, and PLL connections to the microcontroller [10]. A list of considerations provided in the datasheet specify that ceramic decoupling capacitors be placed physically close to each supply pair, low ohmic low inductance connections be used between VSS1, VSS2, and VSSR, VSSPLL be direction connected to VSSR, traces in the oscillator circuit be as short as possible, and that no signals be routed beneath the oscillator circuit. These specifications were covered by the suggested PCB layout in the document, which is closely followed including the copper pour under the microcontroller.

This solid layout for powering the microcontroller will go a long way toward ensuring proper operation free of avoidable noise sources.

The final set of hard general electrical constraints come from the PCB manufacturer [35] and define minimum trace, spacing, and via sizes. The board thickness must fall between .020" and .125", traces greater than .0049", spacing greater than .0045", and finished hole size greater than .010". With these restrictions in mind, signal traces are routed with at least .012" width and finished holes are no less than .015" wide, to be at least the signal trace width with an additional tolerance to remain well above the manufacturer's minimum.

The remaining electrical considerations are simply good design practices and regarded as soft, yet very important, constraints to suppress and reduce the reception of noise. The Motorolla Application Note AN1259 [36] is used as the main source of considerations, of which the following were applied:

- Connectors to external peripherals are placed physically close to their location
- Clock signal traces are as short as possible and have nothing under them
- 45-degree angles are used for all turns, and no acute angles exist
- The power circuit is physically far from the remaining circuit
- Power and ground loops are avoided and wider traces are used (40+ mil)
- Crossing signals are routed perpendicular to each other
- Pixel clock signals are routed keeping distance from other signal lines
- Ceramic capacitors are located next to each supply pair for each IC

A power grid consisting of 60mil traces around the outer perimeter of the circuit is incorporated, and 40mil traces are used to bring power signals toward the center of the board. Since the bottom of the PCB is lightly populated, a ground plane is created by the use of a copper pour covering much of the circuit area. This plane is connected to the copper pour beneath the microcontroller by a via near the center, and care is taken to prevent any loops on the power and ground lines. These major noise reduction considerations are the applicable soft constraint suggestions, and all are successfully implemented.

Beyond the general layout issues are specific considerations for each major component of the system, and are considered from a bottom up design process. These points define the link between the PCB design and the schematic design, and as such they closely parallel the information presented in the schematic considerations. Beginning with the microcontroller, the

most important requirement, next to the suggested circuit provided by the manufacturer mentioned above, is simply making logical pin assignments. With the microcontroller orientation already determined, data is able to be routed to convenient pins while keeping the [Y7:Y0] and [U7:U0] pixel data busses and the [DB7:DB0] LCD data bus routed in order to nearby full register ports. This scheme allows data to be easily manipulated on these bus lines by addressing their respective registers, and also provides close, non-overlapping traces directly to the headers. Port pin assignments are determined in this fashion, which allows a majority of data traces to be routed on the top side of the board. Pin assignments requiring specific functions (PWM, ADC, I^2C) determine the location of the associated header requiring these connections, but these are still conveniently routed despite the additional constraint. The exception to this, unfortunately, is the two I^2C signals which must be routed relatively far from the microcontroller. These signals end up crossing the camera data bus at non-perpendicular angles, but since the I^2C communication is mainly used for initialization of camera registers at startup, this activity is mutually exclusive with pixel data and is therefore not a large concern. After careful planning, and a bit of luck, the oscillator and PLL circuits fall comfortably on the remaining side of the microcontroller not yet claimed by headers or I/O traces. This allows the manufacture's suggested layout to be followed closely and eliminates the need for any routing under this section, helping to keep the noise issues down. The final microcontroller consideration was providing access to the background debug pin, as well as the remaining programming pins, which all are routed out to a programming header.

The next largest, and arguably most critical, component is the OV6620 camera module [26]. As mentioned above, the PCLK, HREF, and VSYNC critical timing signals are routed between ground traces to the microcontroller and are kept as short as possible. Bypass capacitors used for the camera IC are already included on the module, so no additional power considerations are required in the layout. With regards to pixel information, although only the Y data is used, both Y and UV data busses are routed to the microcontroller going to ports PT and PB in order to provide easier data manipulation in code. UV data is ignored, but is accessible if eventually needed. As mentioned above, the I^2C lines must be routed to the appropriate port pins located on a different side of the microcontroller, but can be freely routed on the nearly vacant underside. All other control signals are routed to general I/O port pins based on minimizing the distance of each trace.

The third significant component requiring numerous signal lines is the LCD module and associated electronics [27]. Placed on the opposite side of the microcontroller as the camera module, the LCD header is near plenty of port pins for both the parallel data bus and the various control signals. Once again, the bypass capacitors are included on the LCD module and therefore are not considered. The contrast potentiometer and backlight pushbutton header used with the display are mounted close to the header, keeping the entire LCD circuit to a confined and convenient area.

The remaining components and connectors are placed to keep traces short, with a few additional considerations. The power circuit includes a voltage regulator in a large package which requires the board length to be stretched to accommodate the entire circuit. This works out well for isolating the power system from the remaining components and the created board space allows for the placement of a 20-pin expansion DIP socket and headers. The set of trimmer potentiometers are mounted on the underside of the board such that they will be accessible from the bottom of the package. Although this is seemingly an inconvenient location, it is actually desired for this system since the potentiometers are used rarely and only for calibration. The servo headers are located near their PWM control signal ports, while the pushbutton header is placed near the most accessible of the remaining I/O outputs. With each component location optimized for short signal routing, and with the proper port pin selection for natural flow, a very compact and straightforward PCB is created.

10.0 Software Design Considerations

10. 1 Software Design

The most significant consideration in the project's software design is that the image acquisition and processing must take priority over all other functions. This is accomplished by setting the VSYNC interrupt as the highest priority interrupt, and the HREF interrupt as the second highest priority interrupt. When images are processing, no interruptions are allowed until processing has completed. By examining the flowcharts in Appendix A, it can be seen that the only task of the main loop is to poll the push buttons. PWM generation requires no interrupts or updating until the duty cycle needs to change, which is handled by the image processing interrupts. The real time clock is updated by counting pulses that occur on timer channel 7

(which occur every 20 ms) and calculating the current time relative to that value. An interrupt is triggered approximately every 43 minutes due to the pulse accumulator overflowing, which updates the real time clock in memory. The image acquisition is handled by the VSYNC and HREF interrupts. Once a full image is acquired, all subsequent images are ignored until the image is finished processing and the motors have moved.

The application code is stored in flash. Static messages (such as calibration prompts) are also be stored in flash. Fourteen kilobytes of SRAM are available for use, starting at address $0800 and going to $3FFF. The reference frame data starts at address $0B54 and runs to address $3D6F (12.5kB). The difference data starts at address $0800 and ends at $095F (249 bytes). Single byte values such as calibration settings, flags, and counters are stored starting at $0960, and ends at $0B3B. This should leave plenty of room for the stack, which begins at $3FFE and grows down, and in the worst case should not grow past $3F9E. There is no dynamic memory allocation so no heap is required.

The integrated peripherals required are the analog to digital converter, timer module, and IIC module. Two ATD converters are enabled (register ATDCTL2) and turned to scan mode (ATDCTL5) in order to calibrate. They are also set to 10-bit resolution (register ATDCTL4). Once the calibration is complete the ATD converters are shut off.

The IIC bus needs to be configured to communicate with the camera. The IIC protocol is an enhanced version of the I^2C protocol but is still backwards compatible with I^2C. The frequency divide register (IBFD) is used to drop the clock speed to 100KHz. The control register (IBCR) is used to turn on the IIC peripheral. From then on, data is placed in the data register (IBDR) and the IBCR is used to initiate start and stop conditions. The status register (IBSR) is checked to see if a successful transmission occurred.

The timer module uses the TIOS register to set channel 7, 5, and 3 as output compare channels. The output compare circuitry is connected to the pin by asserting the respective bits in the OC7M register. OC7D is used to set up the counter resets. The timer module is enabled and a pre-scalar is set by using register TSCR2. During operation, TC3, TC5, and TC7 are set in order to toggle the port pin at the correct time, producing a 50Hz signal at a variable duty cycle on pins OCM3 and OCM5.

The microcontroller communicates with a few off-chip peripherals. The LCD is connected to port A. The potentiometers are each connected to an ATD pin. Camera clock

signals are connected to port J (PCLK and VSYNC) and port H (HREF), which supports interrupt triggering. The camera luminance data is received on port P. Push buttons come into general purpose I/O pins.

10.2 Software Design Narrative

For this project the code is broken into the following modules: real time clock, calibration, I^2C communication/camera initialization, push button detection, LCD functions, and image capture and processing. The camera module used in the project accepts registers settings through I^2C commands. The camera initialization is performed by sending the camera's slave address out on the serial bus (0xC0), followed by pairs of 8-bit values. The first of the pair represents the register value on the camera to set and the second of the pair represents the value to write to the register. Upon startup, five camera settings must be adjusted: adjusting the speed of the camera to a 850KHz pixel clock rate, setting the resolution to QCIF (176x146 pixels), and adjusting the pixel clock so that it only runs while image data is being sent instead of being free running, and changing the percentage of lightness and darkness in each picture to ensure each frame taken has enough light.

PWM signals are generated by the timer module. PWM generation requires no interrupts. PWM signals are generated by connecting output compare circuitry to timer pins. Timer counters run up to a certain value, toggle the port pin at that value, reset, and begin to run up again. By adjusting the counter limits and the timer pre-scalar, PWM signal frequencies and duty cycles change. The timer is configured to generate a 50Hz signal, and the duty cycle can be changed by adjusting register values.

The calibration module uses two ATD converters to read in potentiometer values and calibrate the motors. The potentiometer values are used to adjust the tilt and pan motors in order to align them with the camera field of view. During the calibration, a static image with three black squares and a plain white background is held up for the camera to see. The user points to each of the three squares and hit a button to register the coordinates of each square. After calibration the microcontroller finds a linear relationship between the three squares and uses it to associate image coordinates with PWM values.

The pushbutton polling module simply reads the value of the pushbutton lines on the input ports. If a pushbutton is detected high, a flag is set corresponding to that pushbutton for a

small amount of time. Push buttons are only scanned every once in a while to eliminate bounced values being read and to not waste CPU cycles. The pushbutton module routines are used in both the main loop to scroll through LCD information, the calibration module to set an adjustment, and in the real time clock module to set the initial time at startup.

The LCD module has functions to control the LCD. The LCD uses a standard parallel interface and is controlled by a three control signals and 8 data bits. The LCD module contains functions that can initialize the LCD screen, clear the LCD screen, or display characters and output messages to the LCD screen.

Image acquisition relies on two interrupts. At startup, the code listens for a low to high transition on the VSYNC signal sent from the camera. This triggers an interrupt and allows the camera to acquire data and store the initial frame, known as the reference frame. The microcontroller waits for an HREF interrupt. Once an HREF interrupt is received the microcontroller decides if it wants the current row or not. If so, each time a new pixel is ready, the PCLK signal sent from the camera transitions from low to high. When pixel data is valid, it is stored. Once the reference frame is acquired, a flag is set in memory to signify that a reference frame is no longer needed. From then on, each time a VSYNC interrupt triggers, the microcontroller decides if it wants to use the current frame or not. It rejects the frame if it is still processing the previous frame, and disable the HREF interrupts until a new VSYNC interrupt triggers and it reevaluates whether it is ready for a new image or not.

When the microcontroller decides it is ready for a new frame, it begins to acquire the frame pixel by pixel and compare each pixel with the pixel in the reference frame at the same coordinates in the image. If the absolute value of the difference between the two pixels crosses a certain threshold (0x19), the algorithm records the difference data by incrementing two values by one: one associated to all of the pixels in its row and one associated with all of the pixels in its column. After all the differences have been counted, the image processing algorithm runs through all the difference data, find the row and column with the largest difference values. Finally, the image processing algorithm sets the PWM signals to point the laser at that target.

11.0 Version 2 Changes

A second version of the Motion Tracking Camera Platform would include both changes in the current design and additional features. Changes to the circuit would include a more powerful microcontroller capable of running at high clock speeds than 25MHz to obtain a high frame rate, and one in which could at least store one image at QCIF resolution. With these hardware improvements, more advanced image processing algorithms could be employed to provide more intelligent object detection and motion prediction to allow for more fluid servo movements. Additional features would include an easier, more accurate method of calibration, and a remote management system. A wired or wireless connection to a computer terminal would allow easy access to system settings and would allow for remote monitoring, including access to timestamp information and even entire images saved from each motion event. These upgrades would create a much more useful system for any of the potential applications.

12.0 Summary and Conclusions

The Motion Tracking Camera Platform project successfully completed and demonstrated all required project specific success criteria as well as the provided project outcomes. Along with working through the entire design process, a working prototype was made and many professional aspects were analyzed. Among these reports were a social and environmental impact analysis, a safety and reliability analysis, and a patent liability analysis.

Providing insight into real-world design, realistic project constraints were placed on the project and provided experience into actual engineering design. Schematic and PCB techniques were exercised throughout the semester, as were the many technical issues associated with both hardware and software implementations. Assembly coding skills were utilized and improved upon, allowing for an efficient final design. Background knowledge was strengthened and expanded upon as design issues were discovered in practice, and communications skills, both written and oral, were emphasized and improved.

As the semester progressed, it became more apparent that things rarely go according to plan and it is important to have a timeline and schedule for unexpected delays. The importance of teamwork and maintaining a friendly atmosphere became apparent during the final weeks, and sleep was the reward for a successful, early completion. All assignments were completed on

time, and the final product met and exceeded the expectations of each member. The success of the Motion Tracking Camera Platform will provide an excellent foundation for handling future tasks.

13.0 References

[1] OV6620 Color Camera Data Sheet, OmniVision, 1999 June 2
Available HTTP: http://ovt.com/pdfs/pb_6120_6620.pdf

[2] Kodak KAC-9630 Product Page, Kodak, September 2004
Available HTTP: http://www.kodak.com/global/en/digital/ccd/products/cmos/KAC-9630/indexKAC-9630.jhtml?id=0.1.10.4.13&lc=en

[3] Freescale Microcontroller MC9S12XDP512 Page, Freescale Semiconductor
Available HTTP:
http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=MC9S12XDP512&nodeId=0162468636K100

[4] Freescale Microcontroller MC9S12DP512 Page, Freescale Semiconductor
Available HTTP:
http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=MC9S12DP512&nodeId=0162468636K100

[5] United States Patent and Trademark Office Website, [cited 2006 May 1]
Available HTTP: http://www.uspto.gov

[6] Toshio Kamei, "Method and system for tracking a fast moving object", U. S. Patent 6,819,778, March 29, 2001
Available HTTP: http://patft.uspto.gov/netacgi/nph-Parser?patentnumber=6819778

[7] Yoshinori Kuno, Kazuhiro Fukui, Hiroaki Nakai, "Display monitoring system for detecting and tracking an intruder in a monitor area", U. S. Patent 5,243,418, November 27, 1991
Available HTTP: http://patft.uspto.gov/netacgi/nph-Parser?patentnumber=5243418

[8] United States Patent and Trademark Office Website, [cited 2006 May 1]
Available HTTP:
http://www.uspto.gov/web/offices/pac/mpep/documents/2100_2186.htm#sect2186

[9] Reliability Prediction of Electronic Equipment, MIL-HDBK-217F, 1991 Dec 2
Available HTTP: http://shay.ecn.purdue.edu/~dsml/ece477/Homework/Spr2006/Mil-Hdbk-217F.pdf

[10] "MC9S12DP512CPV Device Guide", Freescale Semiconductor, July 2005
Available HTTP:
http://www.freescale.com/files/microcontrollers/doc/data_sheet/9S12DP512DGV1.pdf

[11] LTC1174-5 DC/DC Converter Data Sheet, Linear Technologies, 1994
Available HTTP:
http://www.linear.com/pc/downloadDocument.do?navId=H0,C1,C1003,C1042,C1032,...

[12] OV6620 CIF Color Digital Camera Data Sheet, OmniVision, Ver 1.4, 2000 May 13
Available HTTP: http://www.roboter-teile.de/datasheets/OV6620.pdf

[13] S6A0069X Product Page, Samsung Semiconductors, [cited 2006 Apr 13]
Available HTTP:
http://www.samsung.com/Products/Semiconductor/DisplayDriverIC/MobileDDI/BWSTN...

[14] G. Novacek, "Designing for Reliability, Maintainability, and Safety," Circuit Cellar, issue 125-129, Jan 2001
Available HTTP: http://shay.ecn.purdue.edu/~dsml/ece477/Notes/PDF/4-Mod13_ref.pdf

[15] "Pollution Prevention for Printed Circuit Board Manufacturing," California Environmental Protection Agency, 2005 July 12
Available HTTP: http://www.calgold.ca.gov/P2/3672.htm

[16] "Effects of Lead on Human Health," HCSC, February 2004
Available HTTP: http://www.hc-sc.gc.ca/iyh-vsv/environ/lead-plomb_e.html

[17] "Health Effects of Mercury," CCOHS, 1998 December 21
Available HTTP:
http://www.ccohs.ca/oshanswers/chemicals/chem_profiles/mercury/health_mercury.html

[18] "Duracell: Battery Disposal," Duracell, [cited 2006 May 1]
Available HTTP: http://www.duracell.com/care_disposal/disposal.asp

[19] "Engineering Education Reform: A Trilogy," Frank G. Splitt, January 2003
Available HTTP:
http://shay.ecn.purdue.edu/~dsml/ece477/Homework/Spr2006/enviro_refs.pdf

[20] "Tips on Electrical Safety," Hudson Gas & Electric Co, [cited 2006 May 1]
Available HTTP: http://www2.centralhudson.com/safety_environ/electrical_safety.html

[21] "Fact Sheet: Printed Circuit Board Manufacturers," Virginia Waste Minimization Program, Vol. 1 Issue 9, 1995 October 24
Available HTTP: http://es.epa.gov/techinfo/facts/vdwm/va-fs6.html

[22] "Printed Circuit Board Recycling," Joint Service Pollution Prevention Opportunity Handbook, May 2003
Available HTTP: http://p2library.nfesc.navy.mil/P2_Opportunity_Handbook/2_II_8.html

[23] "Battery Disposal Guide for Households," Environmental Health and Safety Online, [cited 2006 May 1]
Available HTTP: http://www.ehso.com/ehshome/batteries.php

[24] Creative WebCam Live! Motion Website, Creative Technology Ltd, [cited 2006 May 1]
Available HTTP:
http://www.creative.com/products/product.asp?category=218&subcategory=219&product=13979

[25] x10 MultiView XCam2 Wireless Cameras, x10, [cited 2006 May 1]
Available HTTP:
http://www.x10.com/minisites/security_camera/Wireless_Camera_Motion_Activated_Remote_Control_VCR_Recording.html#

[26] C3088 ¼" Color Camera Module Data Sheet
Available HTTP: http://www.electronics123.net/amazon/datasheet/c3088.pdf

[27] Powertip PC 1202-A Character LCD Data Sheet, Powertip
Available HTTP:
http://www.powertip.com.tw/product/PC%20SERIES/PC%201202A.PDF

[28] GWS NARO STD Servo Motor Specs, Servo Hut, [cited 2006 May 1]
Available HTTP: http://servohut.com/HTML/piconaro.htm

[29] 25MHz AWSCR Ceramic Resonator, Abracon Corporation, January 2003
Available HTTP: http://www.abracon.com/Resonators/awscr.pdf

[30] Vishay Sfernice SMD Potentiometer, Vishay, 2004 January 19
Available HTTP: http://www.vishay.com/docs/51041/ts3y.pdf

[31] Shottky Diode Chip, General Semiconductor, April 1998
Available HTTP:
http://www.ortodoxism.ro/datasheets/GeneralSemiconductor/mXuxxvx.pdf

[32] MIC29150 Voltage Regulator, Micrel, August 2005
Available HTTP: http://www.micrel.com/_PDF/mic29150.pdf

[33] HC9S12 Background Debug Module, Freescale Semiconductor, October 2004
Available HTTP:
http://www.freescale.com/files/microcontrollers/doc/ref_manual/S12BDMV4.pdf

[34] Freescale MC9S12DP512CPV Package Discription, May 2005
Available HTTP:
http://www.freescale.com/files/shared/doc/package_info/98ASS23330W.pdf

[35] 4PCB Standard Manufacturing Capabilities, [cited 2006 May 1]
Available HTTP:
http://www.4pcb.com/pcb_milling_low_quantity_capabilities.htm#convenience

[36] "System Design and Layout Techniques for Noise Reduction in MCU-Based Systems"
Available HTTP:
http://shay.ecn.purdue.edu/~dsml/ece477/Homework/Spr2006/AN1259.pdf

Appendix A: Individual Contributions

A.1 Contributions of David Kristof:

My focus in this project was spread over many different areas throughout the semester. In the beginning I worked on part selection for some of the peripheral components, including the servo motors, the LCD module, and the laser. I also made numerous drawings to support the physical descriptions of the project we had discussed. I created the website and made it easy for the other group members to add/remove things when they wanted. I also worked on software planning for how we were going to read in images and use the raw pixel data to find motion and aim a laser pointer at it. I was also in charge of writing the schematic and theory of operation paper, so I was involved in the design of all the circuits and sections of our project. The circuits that required the most design were the PLL/Resonator circuit and the power circuit. Craig and I worked together on the schematic and PCB a lot in order to make parts easier to route and place on the PCB when we imported the data from the schematic.

Once we received our circuit board, Eric and I worked on populating it. There were a lot of changes made throughout the semester that required us to solder or desolder wires, pins, headers, or sometimes whole sections of the board in order to implement. I did a lot of testing on the servo motors to figure out the range of motion, the range of pulse periods to control it, how much current it would draw, and if they were strong enough to turn a platform with the laser pointer on it. Once the board was populated and most of the components has been connected and tested, Eric pretty much took over the packaging and I switched over to a software role in the project. I worked with Craig briefly discussing how we were going to take the stored difference data from his algorithms and find motion from it. I wrote all the code (in assembly) for the routines that find motion, check thresholds to make sure it's trackable motion, find the center of motion, and convert the center values into pulse periods to control the servo motors and aim them at the location of motion. I designed and coded (in assembly) the entire calibration routine as well. Surprisingly, the find center and motion tracking code did not require much debugging, it worked almost as expected on the second try. The calibration routine took a large amount of debugging in order to get it working though, which is what I spent the majority of my time on during the second to last week. I was also in charge of writing the ethical and environmental concerns paper. The last week I spent mostly on testing and troubleshooting the project; hanging

wait times between reference frames, tweaking calibration, and creating "legs" for the project box to lift the front of the box and aim the lens upward since it was mounted in the box at a downward angle. After that, it was just filming PSSC videos, 362 bonus presentation, and writing lots of papers.

A.2 Contributions of Craig Noble:

As one of the two electrical engineers on the team, my main focus was with the hardware and image processing theory associated with the project. I had originally proposed the project as an idea that would include a signal processing twist, an area that I am personally interested in. I wanted to make sure we used an image sensor instead of a full webcam type product, since we wanted to process raw data quickly and frame grabber software was expensive and slow. I also worked on the microcontroller, pushbutton, and power circuits, including choosing the linear regulator and associated power components. After the initial component selection and circuit design, the bulk of my time was spent working on the PCB layout. I spent a large portion of time working on making the PCB an intelligent, compact design which would not have to be changed later on, including selecting proper component locations and minimizing both trace length and number of vias. The success of this key component lead to minimal fly wiring and allowed us to have a relatively small final product.

In the second phase of the project, the process of debugging the hardware and writing the code, I began to switch to more of a software role. Although I worked to get the servo motors working properly by researching and testing the expected pulse signals, I mainly focused on the timer module code and the image acquisition and processing code. I was able to set up our pulse width modulation signals for the servo motors using the timer module since the PWM block would not generate slow enough pulses. Both servo pulses and the real time clock using the pulse accumulator were managed by the timer module with only one interrupt in total, called when the pulse accumulator overflows approximately once every 45 minutes. I also sketched up the image processing algorithm and tested it using Matlab and images from a digital camera, as well as wrote the assembly code for the final implementation to acquire and process images from the image sensor. The final version of the code allowed us to process images using a pixel clock of around 850MHz, enabling the project to update the positioning in real time. During the

debugging phase, I contributed to getting the image transfer and timer block correctly working and aided other team members with general debugging issues.

As for homework submissions, I was solely responsible for the printed circuit board layout design and the reliability and safety analysis. I also did a share of each of the team assignments, mostly the sections related to my contributions, as well as the CAD drawing for the packaging design. I was also responsible for the components page on the website to help us keep track of data sheets and vendor sites.

A.3 Contributions of Tarun Chawla:

Initially, most of the work done was on a group basis. During the first four weeks I helped research camera choices, motors, and general information about the group project and other potential projects. During week five I wrote the design constraint homework, identifying and analyzing the constraints on our project. I did calculations to determine image sizes, image acquisition and processing speeds, and RAM usage.

During week six I began to learn about Code Warrior. I installed Code Warrior for HC12 on the lab machine and looked at sample embedded C and assembly code. Also, throughout weeks six and seven I helped Craig and David make design decisions that affected the schematic and PCB. I did a lot of data sheet reading for the microcontroller, camera, and LCD to help identify what pins needed to be input/output from the microcontroller and which pins could be used as general purpose I/O and which pins could have interrupts triggered. I was not the only one doing this research, it was a group effort. I also helped research smaller parts (resistors and capacitors). I helped to create the custom footprint for the chosen resonator.

During week eight I prepared my portion of the midterm design review. Since I had written the design constraint paper, I wrote the component selection rationale. I also created the slides for the project overview and for the preliminary software design as I was going to be doing the software narrative report.

During week ten and eleven I wrote sample code to run on an NE64 evaluation board in order to start prototyping the design. Eric and I worked on checking out signals coming out of the camera to determine how to write the software for image acquisition. He and I both wrote the code to communicate to the camera using the IIC module in order to change camera registers. I also wrote sample code to test the scan mode of the ATD converter on the evaluation board. I

also wrote sample code to generate 50Hz signals using the timer channels; though they used interrupts (later on Craig found a way to eliminate all of the interrupts).

During week twelve I began to write the software paper. I created the flowcharts for the software paper and the slides software design TCSP. During week thirteen I wrote code to prototype the LCD module. I also began to create a skeleton file for the final code so that each team member could drop his contribution in easily. By this time Eric had populated the board with the power circuit, the microcontroller, and the resonator circuit. I wrote a heartbeat program to test the microcontroller for when the resonator began to resonate. I also write the time initialization function which prompts the user to set the time when the project is powered on.

During week fourteen I helped debug some hardware problems including power and ground being tied together. After hardware problems were fixed I tried to flash the microcontroller but Code Warrior was giving an error. I spent a few hours on the internet researching the error and found a fix and was successfully able to load a heartbeat program on the microcontroller. I wrote a small test program for the ATD converter to ensure that the ATD pins were soldered on properly (some of them looked questionable). They were fine. I wrote the overall initializations for the chip (turning on and off peripherals, setting input/output pins, enabling interrupts). I helped Eric create flywires for certain pins when he needed a second pair of hands. I wrote an LCD library to make it easy for other group members to use the LCD. I also wrote code to test the LCD on the PCB.

During week fifteen I wrote the timestamping functions. I also wrote the function to update the real time clock. I wrote routines to account for pushbuttons bouncing. At the end of week fifteen and start of sixteen Craig, I, and Eric worked on writing code to get a sample image off the camera. It took two full days but we were finally able to get a recognizable image out. During the last week I helped with misc. things such as helping to debug Craig and David's code, film PSSC videos, and put the finishing touches on the project.

A.4 Contributions of Eric Galamback:

In the beginning of the project I initially researched cameras to use. I was looking for a black and white camera but was unable to find one. I also researched different microcontrollers we could use. We were concerned about image size and were looking into different ways to interface to an external memory. I found a system that would interface a camera, a

microcontroller and an external ram chip. It used a pld or fpga to generate addresses for the external ram so the microcontroller did not need to do any of the overhead associated with storing an image. I made the first iteration of the team webpage. To do so I modified a style sheet that I found on a css tutorial site. While we were researching motors I discovered the motors we were going to buy had the potential to draw two amps of current when they were turning. We would not have been able to source enough current and the project would not function with those motors. I was the author of homework four on packaging. While Dave and Craig were working on the PCB layout I worked on making a custom footprint for the resonator. This was necessary because we could not find a resonator or an oscillator with a known footprint. Also during this time I would research parts of the microcontroller Dave and Craig had not researched. For example, I would look to see if groups of pins needed external pull up or pull down resistors. While researching I discovered that the MC9S12XDP512 does not have as much ram as advertised on the webpage and the ram it does have has to be accessed a page at a time. The lack of RAM made the microcontroller much less desirable and we ultimatley used a different microcontroller. For the midterm design review I made slides for the PSSCs and for the packaging. I also made the handouts for the midterm design review.

Tarun and I worked on camera interfacing during spring break. We needed to see the different timing signals from the camera because the data sheet we were using was very unreliable. I could not plug the camera into the development board because the headers on the development board did not have power and ground for the camera. To solve this I built a test header for the camera. I added a composite video cable to the header and looked at the video output. The camera only has PAL video timing signals so it did not look right but at least I knew the camera was not broken. After that, I prepared hardware for Tarun to test software on. He would tell me what section he was writing code for and I could come up with a way to test it. I found right angle headers for the camera to mount to the PCB and the box that the project is housed in. I was also the author of homework nine on patents. When the PCB came in I built and tested the power supply circuit. Next, I practiced soldering microcontrollers under the microscope and soldered the microcontroller onto our PCB. Next, I worked on the resonator. It did not oscillate when I built it so I investigated the polarity of the resonator and found out they are not polarized. I soldered a wire to a pin on the microcontroller so we could signal the presence of an external oscillator. I had to jump the LCD control signals from a different port

and add a potentiometer for the LCD contrast. I rewired the camera pins so that the VSYNC signal came to an interrupt pin. This was possible because we no longer needed the HREF signal. Later it was discovered that we now needed the HREF signal from the camera. To solve the problem I soldered a wire from the camera header to a pin on the microcontroller. I designed and built all of the packaging. I edited the PSSC videos every time we re-filmed them. Over the whole project I would help debug code with whoever needed help.

Appendix B: Packaging

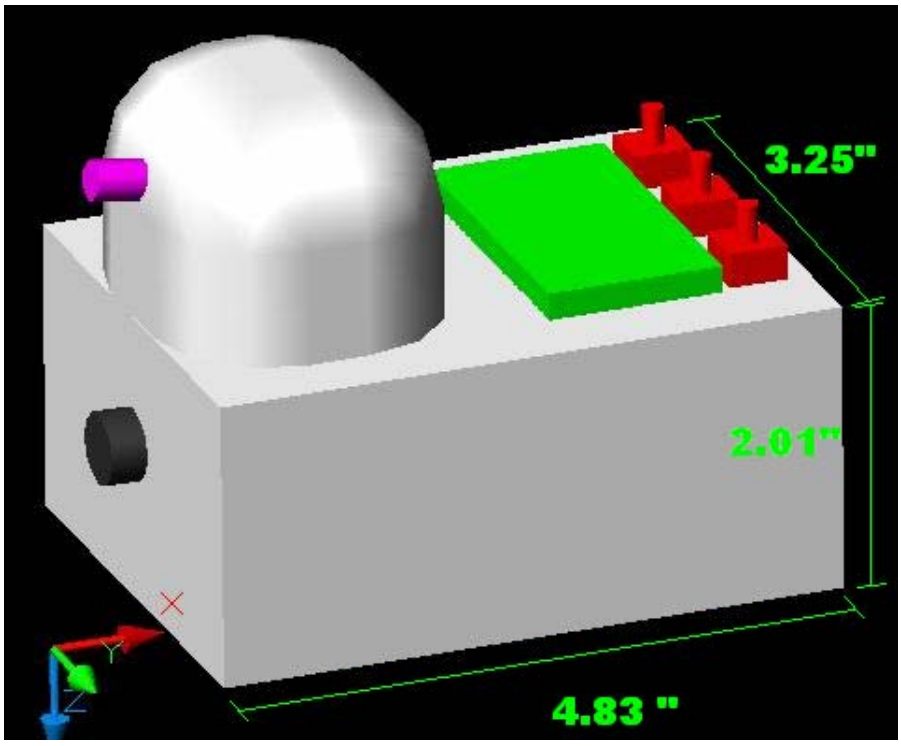

Figure B.1 – Original Proposed Packaging

Figure B.2 – Final Packaging Design

Appendix C: Schematic

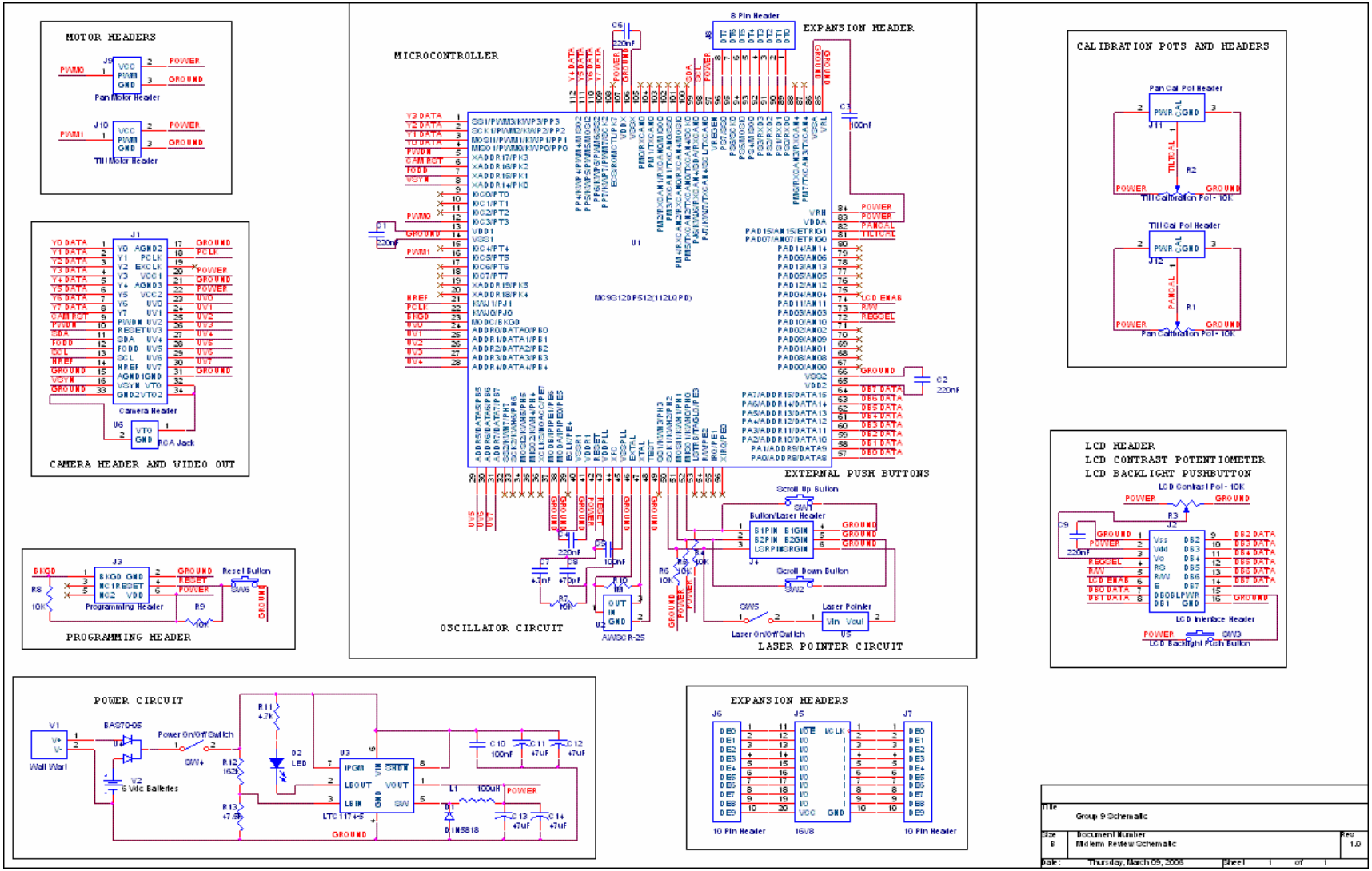

Figure C.1 – Full Schematic

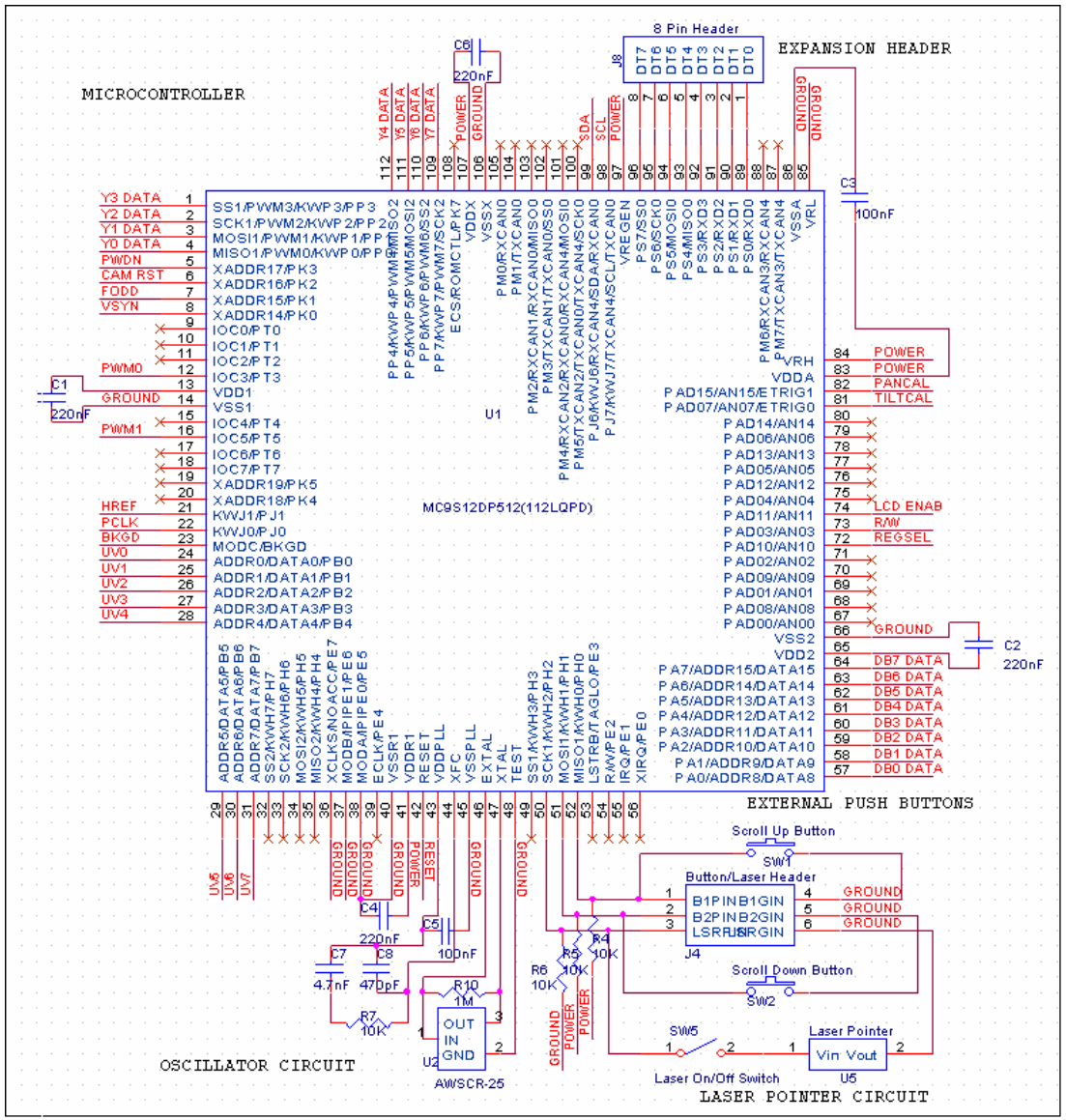

Figure C.2 – Microcontroller Block Schematic

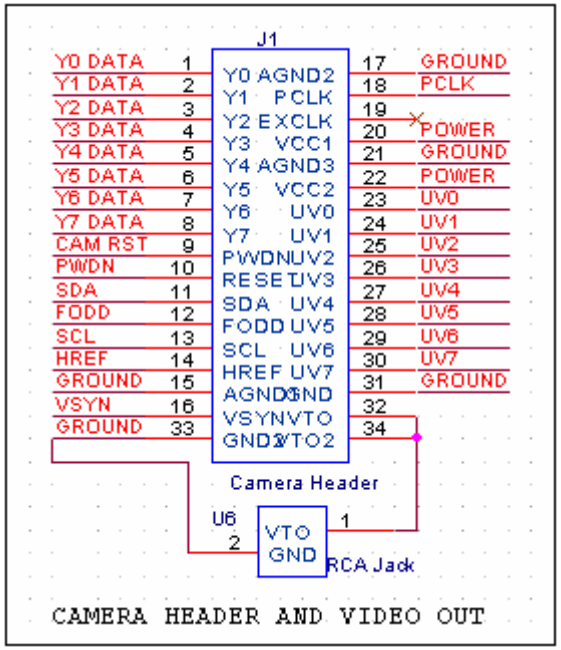

Figure C.3 – Camera Block Schematic

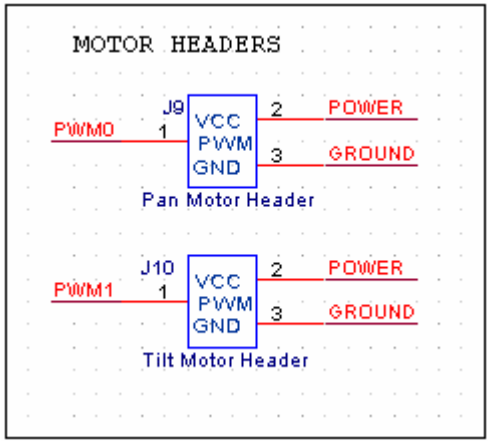

Figure C.4 – Motor Block Schematic

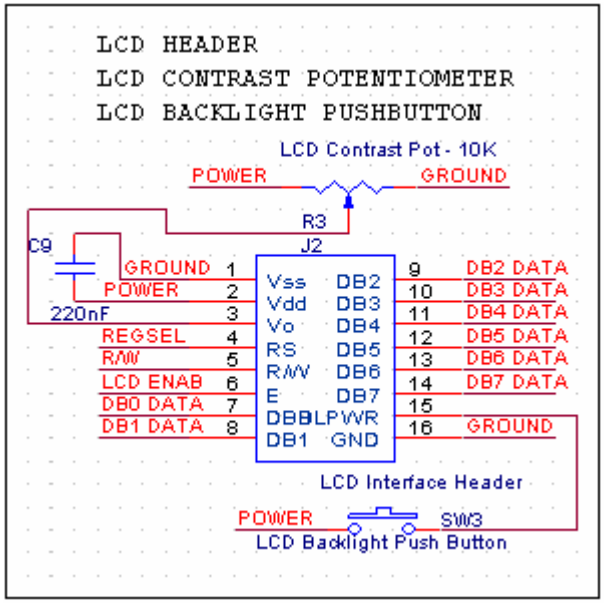

Figure C.5 – LCD Block Schematic

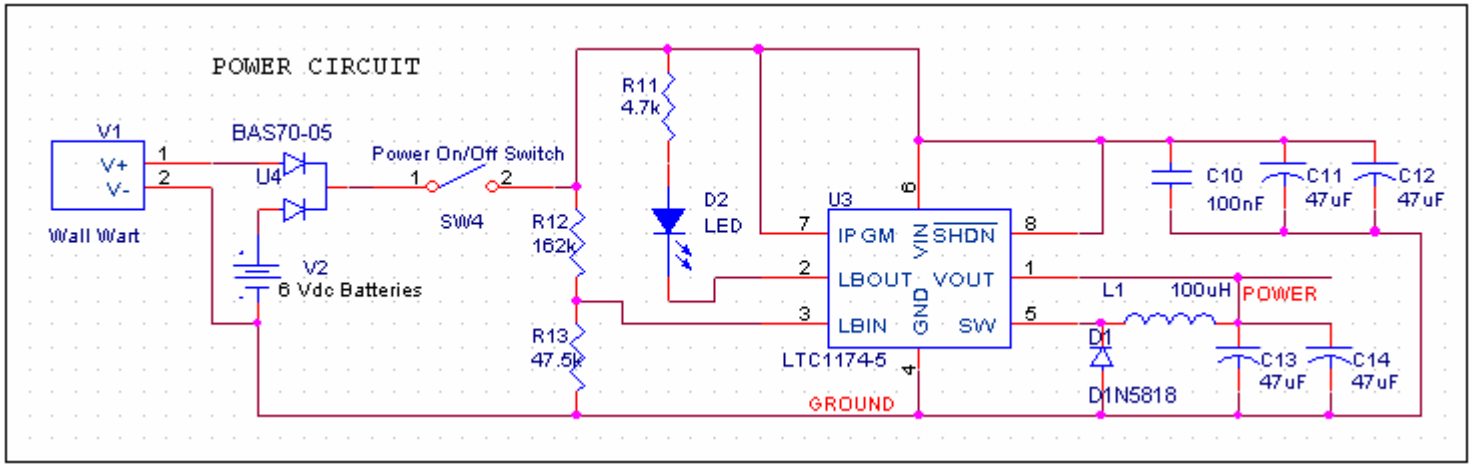

Figure C.6 – Power Block Schematic

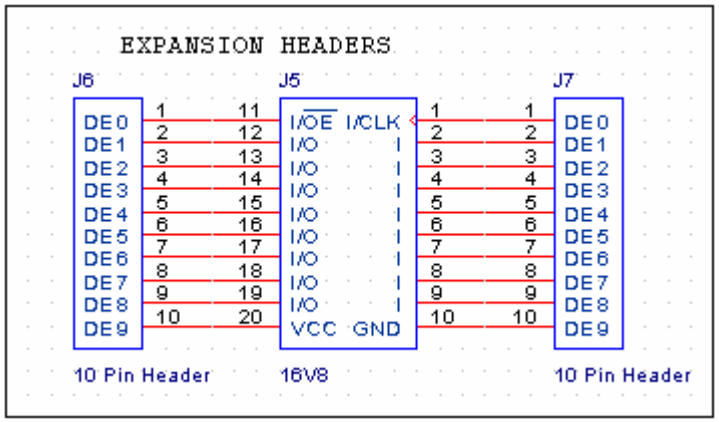

Figure C.7 – Expansion Block Schematic

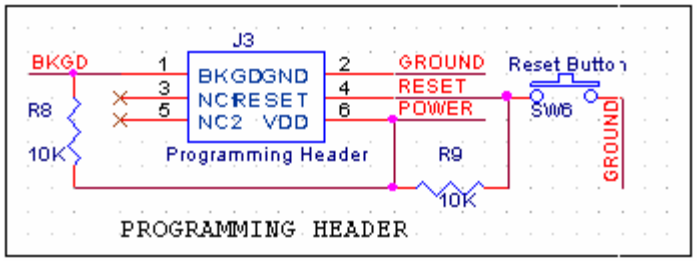

Figure C.8 – Programming Header Schematic

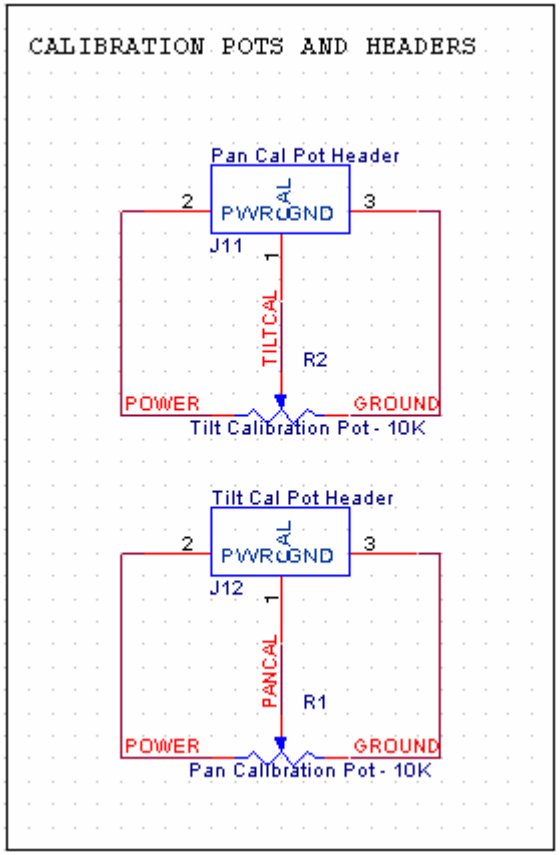

Figure C.9 – Calibration Block Schematic

Appendix D: PCB Layout Top and Bottom Copper

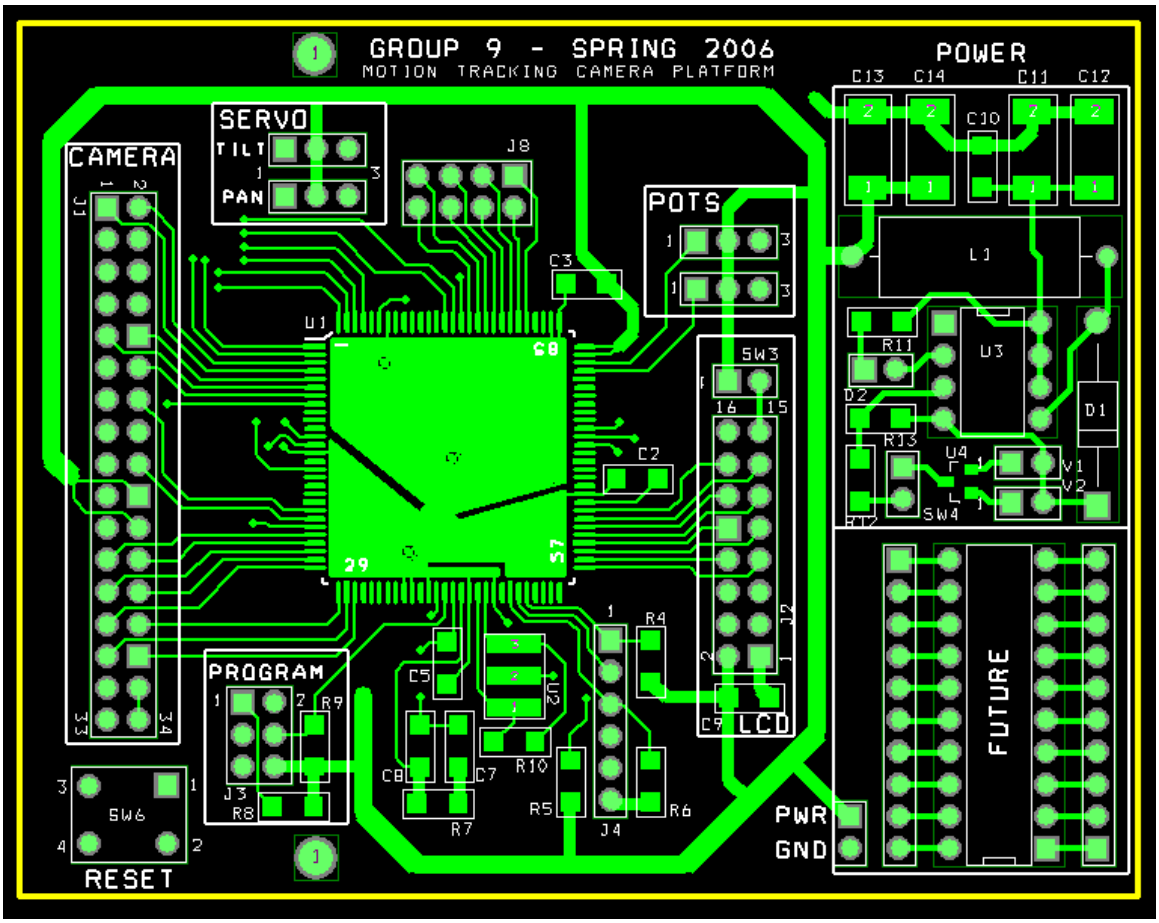

Figure D.1 – PCB Top Layer

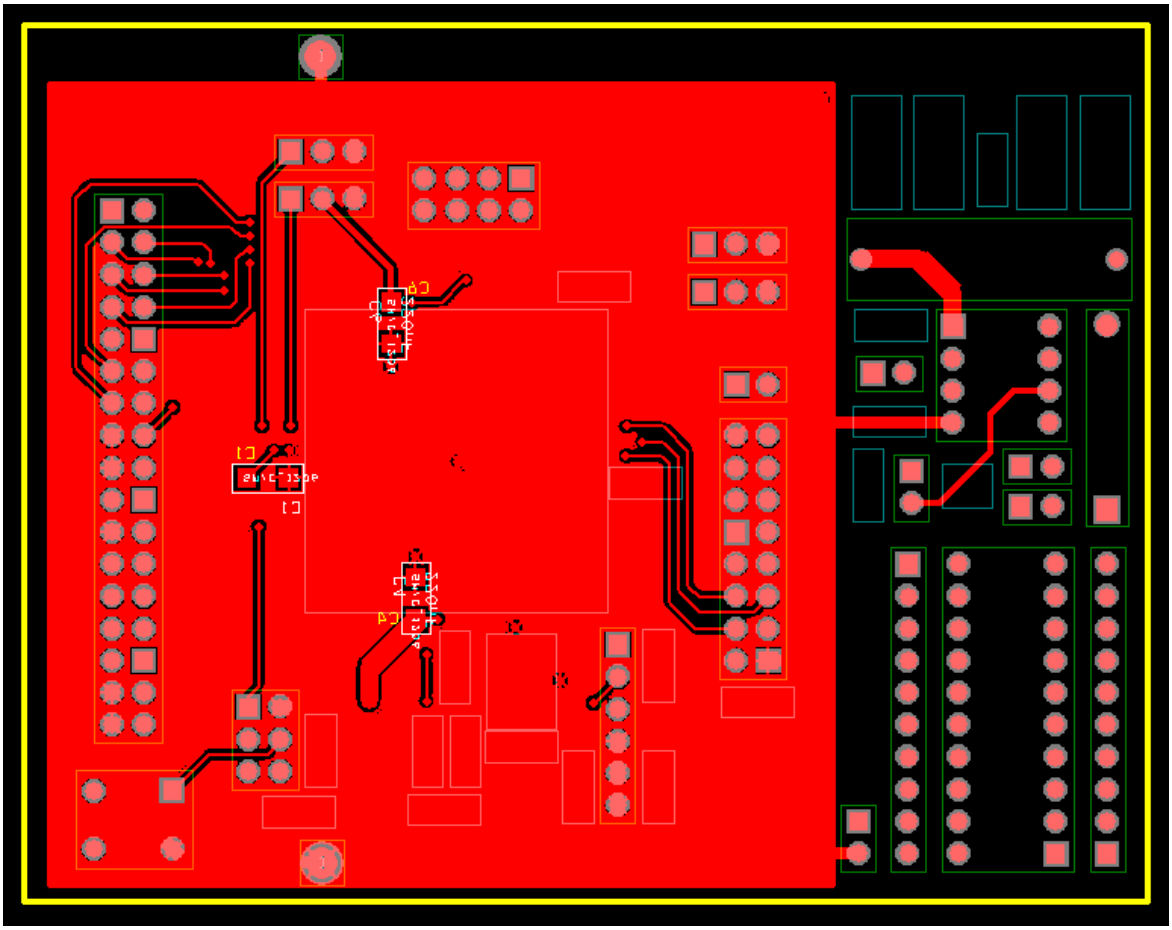

Figure D.2 – PCB Bottom Layer

Appendix E: Parts List Spreadsheet

Vendor	*Manufacturer*	*Part No.*	*Description*	*Unit Cost*	**Qty**	*Total Cost*
Freescale	Freescale	MC9S12DP512	16-bit microcontroller	19.90	1	$19.90
Electronics123	Omnivision	C3088	OV6620 camera module	43.65	1	$43.65
Powertip	Powertip	PC1202-A	LCD	7.95	1	$7.95
Servo Hut	GWS	NARO STD	STD Servo motor	11.00	2	$22.00
Amazon	Sutter's Mill	DA-1900	Laser pointer	16.50	1	$16.50
Digikey	Serpac	Serpac 153	Hobby Box	10.08	1	$10.08
Linear	Linear	LTC-1174CN8-5	Power Regulator	4.35	1	$4.35
				TOTAL		**$124.43**

Appendix F: Software Listing

```
;*****************************************************************
; Team 9
; Motion Tracking System
; Spring 2006
; This is the full source code listing designated for
;   an MC9S12DP512 microcontroller
; Each section has its own heading.
;*****************************************************************

; export symbols
            XDEF Entry        ; export 'Entry' symbol
            ABSENTRY Entry    ; for absolute assembly: mark this as application
entry point

; include derivative specific macros
            INCLUDE 'mc9s12dp512.inc'

;Macro Definitions
lcd_writemode:  MACRO
                movb  #$40,PTS          ;Set R/W to 0 and RS to 1
                ENDM

lcd_settingmode:MACRO
                movb  #$00,PTS          ;Set R/W and RS both to 0
                ENDM

ts_updateclk:MACRO
               pshx
               pshd
               ldx    #$0019    ;divide PACN3 by 25
               ldd    PACN3
               idiv
               tfr    x,d
               ldx    #$003C    ;divide remaning by 60 to get seconds
               idiv
               stab   rtc_tempsec
               tfr    x,d
               stab   rtc_tempmin

               ;have all the values needed, now need to add them together

                   ldaa   rtc_seconds
                   adda   rtc_tempsec
                   staa   rtc_tempsec

                   ldaa   rtc_minutes
                   adda   rtc_tempmin
                   staa   rtc_tempmin

                   movb   rtc_hours,rtc_temphr


                   ;now correct the values to get the current time
```

```
                    ldaa   rtc_tempsec
                    cmpa   #$3C
                    blt    ts_skipincmins
                    inc    rtc_tempmin
                    suba   #$3C
                    staa   rtc_tempsec

ts_skipincmins

                    ldaa   rtc_tempmin
                    cmpa   #$3C
                    blt    ts_skipinchrs
                    inc    rtc_temphr
                    suba   #$3C
                    staa   rtc_tempmin

ts_skipinchrs       ldaa          rtc_temphr
                    cmpa          #$18                ;24 hex
                    blt          ts_skiphrreset
                    clra

ts_skiphrreset   staa rtc_temphr
                    puld
                    pulx

                    ENDM

ROMStart    EQU  $4000  ; absolute address to place code/constant data

;***************************************************************
;EQU definitions
;***************************************************************


;Image capture variables
IMGADDR_START   equ  $0B54  ;reference image data location
IMGADDR         equ  $09C4  ;variable for current pixel address
REFIMG          equ  $09C6  ;reference image flag
THLD            equ  $09CD    ;threshhold value for pixel compare
IROW            equ  $09C7  ;variable for current row address
TROW_START      equ  $0A8C  ;first address of temp row data
TEMPROW         equ  $09C9  ;variable for current temp location address
max_col_addr    equ  $08B0  ;last address in column data array
max_row_addr    equ  $08F8  ;last address in row data array
min_col_addr    equ  $0800  ;first address in column data array
min_row_addr    equ  $08B0  ;first address in row data array
WANTFRAME       equ  $09CB  ;flag set if we don't want frame
WANTROW         equ  $09CC  ;flag set if we want row
TROW_END        equ  $0B3C  ;last address of temp row data


;Find center and aiming variables
COL_DATA_ADDR_END EQU $08AF ; address of last col value, uses same variable
space as pclk and vsync
ROW_DATA_ADDR_END EQU $08F7 ; address of last row value, uses same variable
space as pclk and vsync
```

```
COL_DATA_ADDR_START EQU $0800 ; address of first col value, uses same variable
space as pclk and vsync
ROW_DATA_ADDR_START EQU $08B0 ; address of first row value, uses same variable
space as pclk and vsync
NUM_OF_COLS EQU $B0 ; number of cols = qcif = 1/2cif
NUM_OF_ROWS EQU $48 ; number of rows = 1/2qcif = 1/4cif
MAXCOLV EQU $0A51 ; highest value of the columns
MAXROWV EQU $0A52 ; highest value of the rows
MAXCOLV_THRESHHOLD EQU $15 ; maxcolv must be higher than this for motion
MAXROWV_THRESHHOLD EQU $10 ; maxrowv must be higher than this for motion
MINCOLWIDTH EQU $07 ; min width of an object for motion
MINROWHEIGHT EQU $07; min height of an object for motion
OBJECT_EXIST EQU $0A53 ; 1 means you're in an object, 0 means you're not
END_OF_OBJECT EQU $0A54 ; index of the end(beginning) of the object you are
currently in
COL_INDEX EQU $0A55 ; stores current column index
ROW_INDEX EQU $0A56 ; stores current row index
MAX_OBJECT_WIDTH EQU $0A57 ; stores the width of the largest object so far
COL_OBJECT_CENTER EQU $0A58 ; stores the center value of the columns,
determines where to aim laser
ROW_OBJECT_CENTER EQU $0A59 ; stores the center value of the rows, determines
where to aim the laser
TEMP_PRODUCT EQU $0A5A ; temp 16 bit variable for storing mul data, !!!USES
SAME ADDR AS OBJECT_EXIST/END_OF_OBJECT!!!
COLS13 EQU $3A ; 1/3 col value
COLS23 EQU $76 ; 2/3 col value
ROWS13 EQU $18 ; 1/3 row value
ROWS23 EQU $30 ; 2/3 row value
COL_OBJ1 EQU $0A28 ; col center value of the first object
COL_OBJ2 EQU $0A29 ; col center value of the second object
COL_OBJ3 EQU $0A2A ; col center value of the third object
ROW_OBJ1 EQU $0A2B ; row center value of the first object
ROW_OBJ2 EQU $0A2C ; row center value of the second object
ROW_OBJ3 EQU $0A2D ; row center value of the third object
COL_PWM1 EQU $0A2E ; 2 byte pwm value needed to aim pan at the first object
COL_PWM2 EQU $0A30 ; 2 byte pwm value needed to aim pan at the second object
COL_PWM3 EQU $0A32 ; 2 byte pwm value needed to aim pan at the third object
ROW_PWM1 EQU $0A34 ; 2 byte pwm value needed to aim tilt at the first object
ROW_PWM2 EQU $0A36 ; 2 byte pwm value needed to aim tilt at the second object
ROW_PWM3 EQU $0A38 ; 2 byte pwm value needed to aim tilt at the third object
COL_SLOPE1 EQU $0A3A ; 2 byte pwm per pixel col slope 1
COL_SLOPE2 EQU $0A3C ; 2 byte pwm per pixel col slope 2
COL_SLOPE3 EQU $0A3E ; 2 byte pwm per pixel col slope 3
ROW_SLOPE1 EQU $0A40 ; 2 byte pwm per pixel row slope 1
ROW_SLOPE2 EQU $0A42 ; 2 byte pwm per pixel row slope 2
ROW_SLOPE3 EQU $0A44 ; 2 byte pwm per pixel row slope 3
COL_SLOPE_AVG EQU $0A46 ; 2 byte average col slope pwm/pixel !! IMPORTANT
VARIABLE, DO NOT USE THIS ADDR !!
ROW_SLOPE_AVG EQU $0A48 ; 2 byte average row slope pwm/pixel !! IMPORTANT
VARIABLE, DO NOT USE THIS ADDR !!
COL_AIM_OFFSET EQU $0A4A ; 2 byte offset for aiming pan motor !! IMPORTANT
VARIABLE, DO NOT USE THIS ADDR
ROW_AIM_OFFSET EQU $0A4C ; 2 byte offset for aiming tilt motor !! IMPORTANT
VARIABLE, DO NOT USE THIS ADDR
CAL_REF_IMG EQU $0A4E ; variable to tell find center you are in calibration,
run special find objects
```

```
MOTION_DETECTED EQU $0A4F ; variable to tell timestamp routine if you are in
motion or not
TEMP_VAR7 EQU $0A50
PWM_MINV EQU $0500
PWM_MAXV EQU $0B00
REF_FRAME_COUNTER1 EQU $0A5C
REF_FRAME_COUNTER2 EQU $0A5D
CAL_THOLD EQU $10

;Real time clock variables
rtc_hours       equ  $0960  ;current time hours
rtc_minutes     equ  $0961  ;current time minutes
rtc_seconds     equ  $0962  ;current time seconds
rtc_decisecs    equ  $0988  ;current time tenths of a second
rtc_temphr      equ  $0909  ;temporary hours
rtc_tempmin     equ  $090A  ;temporary minutes
rtc_tempsec     equ  $090B  ;temporary seconds
rtc_tempdeci    equ  $090C  ;temporary deciseconds
rtc_temppa      equ  $090D  ;upper byte for tempPA
;rtc_temppa2    equ  $090E  ;lower byte for tempPA


;Timestamp variables
ts_current      equ   $0963  ;current timestamp to display
;ts_current2    equ   $0964  ;One word pointer
ts_buffer       equ   $0965  ;start of timestamp buffer, 10 entires, 30 bytes
ts_endbuffer    equ   $0983  ;end of timestamp buffer
ts_numstamps    equ   $0984  ;number of timestamps currently recorded
ts_pointer      equ   $0985  ;Where to currently write to in the timestamp
buffer
;               equ   $0986  ;One word pointer
ts_current_lit  equ   $0987  ;Literal current position (not a pointer, value)
ts_bufferm1     equ   $0962  ;Constant to tell if we have scrolled down below 1
;Message lookup table beginning
lcd_msglookup   equ  $4000    ;beginning of the lookup table
;Message table entries
ts1             equ  $01
ts2             equ  $02
ts3             equ  $03
ts4             equ  $04
ts5             equ  $05
ts6             equ  $06
ts7             equ  $07
ts8             equ  $08
ts9             equ  $09
ts10            equ  $0A
settimenow      equ  $0B
nodata          equ  $0C
todisplay       equ  $0D

; variable/data section
            ORG RAMStart
; Insert here your data definition. For demonstration, temp_byte is used.



            ORG ROMStart
```

```
;*************************************************************
;LCD Lookup Table
;*************************************************************
;Every message must be 12 characters


       ;     org lcd_msglookup ;Start of lcd lookup table in flash
       ;DON'T ADD TO THE FRONT OF THE LOOKUP TABLE PLEASE!!!!!
       ;It will mess up my timestamp code :(
       ;To use, load the string number in register A
       ;And jsr to lcd_topmsg or lcd_bottommsg
       ;To clear the LCD use lcd_clrscreen
            fcb "Dummy String"     ;String 00
            fcb "Timestamp 1 "     ;String 01
            fcb "Timestamp 2 "     ;String 02
            fcb "Timestamp 3 "     ;String 03
            fcb "Timestamp 4 "     ;String 04
            fcb "Timestamp 5 "     ;String 05
            fcb "Timestamp 6 "     ;String 06
            fcb "Timestamp 7 "     ;String 07
            fcb "Timestamp 8 "     ;String 08
            fcb "Timestamp 9 "     ;String 09
            fcb "Timestamp 10"     ;String 0A
            fcb "Set Time Now"     ;String 0B
            fcb "No Data     "     ;String 0C
            fcb "            "     ;String 0D
             fcb "Calibration " ;0E
             fcb "Exit anytime" ;0F
             fcb "Set Cal Img " ;10
             fcb "   Done?    " ;11
             fcb "Move Obj 1 L" ;12
             fcb "Move Obj 1 U" ;13
             fcb "Move Obj 2 R" ;14
             fcb "Move Obj 2 L" ;15
             fcb "Move Obj 2 D" ;16
             fcb "Move Obj 2 U" ;17
             fcb "Move Obj 3 R" ;18
             fcb "Move Obj 3 D" ;19
             fcb "AIM LASER AT" ;1A
             fcb "TOP LEFT OBJ" ;1B
             fcb "MIDDLE OBJ  " ;1C
             fcb "BOTRIGHT OBJ" ;1D
             fcb "COL AIM DOES" ;1E
             fcb " NOT WORK   " ;1F
             fcb "COL OFFSET  " ;20
             fcb " TOO HIGH   " ;21
             fcb " TOO LOW    " ;22
             fcb "ROW AIM DOES" ;23
             fcb "ROW OFFSET  " ;24
             fcb "CALIBRATION " ;25
             fcb "COMPLETE!   " ;26
             fcb " RE-ALIGN   " ;27
             fcb "  CAL IMG   " ;28
             fcb "  CAL IMG   " ;29
             fcb "INITIALIZING" ;2A
             fcb "Please wait " ;2B
             fcb "Done!       " ;2C
```

```
            fcb " Calibrate? " ;2D
            fcb " No or Yes  " ;2E
            fcb "   Ready    " ;2F

;*************************************************************
;Code Entry Point
;*************************************************************


Entry:      sei
            lds   #$3FFF      ;Set the stack pointer to the top of RAM

            ;starting variable values
            movb  #$00,WANTFRAME
            movb  #$00,REFIMG
            movb  #$00,CAL_REF_IMG
            movw  #$0029,COL_SLOPE_AVG
            movw  #$002D,ROW_SLOPE_AVG
            movw  #$0741,COL_AIM_OFFSET
            movw  #$07FC,ROW_AIM_OFFSET
            movb  #$B0,THLD
            ;end

            movw #$500, TC3
            movw #$500, TC5

            jsr   systeminit  ;Intialize the overall system (I/O and interrupt
enables)

            jsr   lcdinit     ;Initialize the LCD and set the current time

            jsr   timestamp_init ;Initialize the timestamp buffer

            ldaa  #$2A           ;Output Initialize messages to the LCD
            jsr   lcd_topmsg
            ldaa  #$2B
            jsr   lcd_bottommsg

            jsr   iscinit     ;Initialize the I^2C module

            jsr   camerainit  ;Initialize the camera

            jsr   ectinit     ;Initialize the pwm signals

            jsr   clrimagemem ;clear out the image memory to ensure we are not
using stale data


            ldy   #$0

startupdelay
            iny
             jsr   lcd_polldelay

            cpy   #$100
            bne   startupdelay
```

```
            ldaa  #$2D       ; ask if user wants to calibrate
            jsr   lcd_topmsg
            ldaa  #$2E
            jsr   lcd_bottommsg

calloop
            ldaa  PTH             ;Load Port H
            cmpa  #$01            ;Check button 1
            beq   run_cal      ;If it was pressed, yes calibrate

            ldaa  PTH             ;Load Port H
            cmpa  #$02            ;Check button 2
            beq   no_cal    ;If it was pressed, no calibrate

            bra calloop

run_cal
            jsr   lcd_polldelay
            jsr   atd_init
            jsr   calibrate         ;Run calibration routine
            jsr   atd_turnoff
no_cal
            ldaa  #$2F
            jsr   lcd_topmsg            ; display ready
            ldaa  #$0D
            jsr   lcd_bottommsg
            movb  #$01, REFIMG    ; tell camera to take ref image
            movb  #$19, THLD             ; change threshold back down for
normal operation

            bset  PIFJ,#$02               ;clear interrupt flags
            bset  PIFH,#$43

            cli

mainloop
            ldaa  PTH             ;Load Port H
            cmpa  #$01            ;Check button 1
            beq   tsscrollup      ;If it was pressed, scroll the LCD up

            ldaa  PTH             ;Load Port H
            cmpa  #$02            ;Check button 2
            beq   tsscrolldown    ;If it was pressed, scroll the LCD down

            bra mainloop


tsscrollup
            jsr   lcd_polldelay2
            jsr   timestamp_display_up
            bra   mainloop

tsscrolldown
            jsr   lcd_polldelay2
            jsr   timestamp_display_down
            bra   mainloop
```

```
;*************************************************************
;Clears memory
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

clrimagemem
           ldx      #$0b54            ;clear reference frame
loopt      movb     #$F0,0,x
           inx
           cpx      #$3d00
           blt      loopt

           ldx #$0800
loopt2     movb #$00,0,x              ;clear difference data
           inx
           cpx #$900
           blt loopt2


      rts

;*************************************************************
;System Initialization
;*************************************************************

systeminit:
            ;Starting from pin 1 going counter-clockwise according to schematic

            ;Set Port P DDR
            movb  #$00,DDRP   ;Camera Y data, all inputs

            ;Set Port K DDR
            movb  #%11111100,DDRK   ;Pin 0=HREF,Pin 1=FODD, Pin 2=CmrRst, Pin
3=CmrPWD, Pins 4-7 unused
            bclr  PORTK,#%00001100 ;Ensure the camera is not in permanent reset
or powered down

            ;Set Port T DDR
            movb  #%00101000,DDRT   ;3 and 5 used for PWM outputs, rest unused.

            ;Port J
            movb  #%00000000,DDRJ   ;Pins 6-7 I^2C, Pins 0-1=pclk,vsync, 2-5
not pins

            ;Port B
            movb  #%00000000,DDRB   ;Camera U-V Data

            ;Port H
            movb  #%00000100,DDRH   ;Port H, Pins 7-3 unused, pin 2 laser, pin
1-0, push buttons

            ;Port E
            movb  #%00000000,DDRE   ;Unused pins

            ;Port A
            movb  #%11111111,DDRA   ;LCD Data output pins
```

```
            ;Port M
            movb  #%00000000,DDRM   ;Unused pins

            ;Port S
            movb  #%01100001,DDRS   ;{7,4:1}=unused,6=LCDrs,5=LCDrw,0=LCDeclk

            movb  #$03,PPSJ         ;Change interrupts to trigger on rising
edge
            movb  #$40,PPSH

            ;Interrupt Enables
            movb  #$02,PIEJ         ;Enable VSYNC interrupts
            movb  #$CE,HPRIO        ;Sets PCLK/VSYNC to be highest interrupt



            rts

;*************************************************************
;LCD Initialization
;*************************************************************
;Data comes out on PORTA
;E comes out on PTS(0)
;RS comes out on PTS(6)
;RW comes out on PTS(5)


lcdinit:
               movb  #$00,rtc_hours
               movb  #$00,rtc_minutes
               movb  #$00,rtc_seconds


            ;LCD setting mode.
               lcd_settingmode
               ldaa  #$30
               jsr   long_lcd_write  ;Initialize the LCD, 1
               jsr   long_lcd_write  ;Initialize the LCD, 2
               jsr   long_lcd_write  ;Initialize the LCD, 3

               ldaa  #$38          ;Set 8 bit mode,2 line LCD, character font
               jsr   lcd_write

            ldaa  #$01
            jsr   lcd_write  ;Clear the display

            ldaa  #$06      ;Set the cursor move direction
            jsr   lcd_write  ;Increments cursor after a write to the LCD

            ldaa  #$0F      ;Enables the cursor
            jsr   lcd_write

            lcd_writemode ;Set the LCD to write characters out

            ldaa  #settimenow   ;Output 'set time now' to lcd bottom
            jsr   lcd_bottommsg
```

```
            jsr   lcd_cursorhome
            lcd_writemode

            ldaa  #$30        ;Writes 00:00
            jsr   med_lcd_write
            jsr   med_lcd_write
            ldaa  #$3A
            jsr   med_lcd_write
            ldaa  #$30
            jsr   med_lcd_write
            jsr   med_lcd_write

            lcd_settingmode ;Takes us back to setting mode
            ldaa  #$02
            jsr   med_lcd_write       ;Returns the cursor to the home position
            lcd_writemode

            jsr   timeset_infloop
            rts
timeset_infloop:


            ldaa  PTH             ;Load Port H
            cmpa  #$01            ;Check button 1
            beq   setmins         ;If it was pressed, move to setting minutes

            ldaa  PTH             ;Load Port H
            cmpa  #$02            ;Check button 2
            bne   timeset_infloop         ;If it wasn't pushed poll the buttons
again
            jsr   uphr            ;If it was pressed up the hour counter and
update LCD
            bra   timeset_infloop           ;Then poll again.


setmins     lcd_settingmode   ;Lets us adjust cursor display
            ldaa  #$83
            jsr   long_lcd_write         ;Moves cursor to the minutes position
            lcd_writemode     ;Puts us back into character write mode

setmins2    ldaa  PTH               ;Load Port H
            cmpa  #$01
            bne   minsnotdone         ;Check to see if button 1 was pressed
            rts                     ;Done

minsnotdone ldaa  PTH               ;Load Port H
            cmpa  #$02                ;Check to see if button 2 was pressed
            bne   setmins2            ;If not, poll buttons again

            jsr   upmin                       ;If so, update the minutes

            bra setmins2              ;Poll buttons again

;********
;Uphr function - increments hours by one
;********
```

```
uphr:       clra                    ;Clear the A register for later IDIV
instructions
            ldab  rtc_hours         ;Load the current number of hours
            incb                            ;Incrememement it
            cmpb  #$18               ;If it is equal to 24 or 0x18, reset it
            bne   hrokay
            clrb
hrokay
            stab  rtc_hours         ;Update the value in memory
            ldx   #$000A            ;Get the upper digit
            idiv
            tfr   x,d
            addb  #$30

            tfr   b,a               ;Move the value in port B to port A
            jsr   med_lcd_write         ;Write the character to the LCD
            clra
            ldab  rtc_hours         ;Get the lower digit
            ldx   #$000A
            idiv
            addb  #$30

            tfr   b,a
            jsr   med_lcd_write         ;Write the lower digit to the LCD

            lcd_settingmode   ;Settings mode for LCD
            ldaa  #$02                ;Retrun cursor home
            jsr   med_lcd_write               ;Sends the cursor to the home
position
            lcd_writemode     ;Sets the LCD back to character write mode
            rts
;********
;Upmin function - increments minutes by one
;********

upmin:
            clra
            ldab  rtc_minutes       ;Load the current minutes value
            incb                    ;Increment it
            cmpb  #$3C                ;Check to see if it has hit 60
            bne   minkay
            clrb                            ;If so, clear it
minkay
            stab  rtc_minutes       ;Update minutes in memory
            ldx   #$000A              ;Get the upper digit...
            idiv
            tfr   x,d
            addb  #$30

            tfr   b,a
            jsr  med_lcd_write          ;Output the upper digit to the LCD

            clra                      ;Get the lower digit...
            ldab  rtc_minutes
            ldx   #$000A
            idiv
            addb  #$30
```

```
            tfr   b,a
            jsr   med_lcd_write         ;Output the lower digit to the LCD

             lcd_settingmode   ;Change to setting mode
            ldaa  #$83
            jsr   med_lcd_write         ;Move the cursor back to the minutes
starting position
            lcd_writemode     ;Change back to character write mode
            rts

;*************************************************************
;End LCD Initializations
;*************************************************************

;*************************************************************
;Real time clock functions
;*************************************************************
;Timestamp variables
;ts_current      equ   $0963  ;current timestamp to display
;ts_current2    equ   $0964  ;One word pointer
;ts_buffer       equ   $0965  ;start of timestamp buffer, 10 entires, 30 bytes
;ts_endbuffer    equ   $0983  ;end of timestamp buffer
;ts_numstamps    equ   $0984  ;number of timestamps currently recorded
;ts_pointer      equ   $0985  ;Where to currently write to in the timestamp
buffer
;               equ   $0986  ;One word pointer
;ts_current_lit  equ   $0987  ;Literal current position (not a pointer, value)

;This function initializes the timestamp variables and
;sets the LCD output
timestamp_init:
            movw  #ts_buffer,ts_current
            movb  #$00,ts_numstamps
            movw  #ts_buffer,ts_pointer
            movb  #$01,ts_current_lit
            jsr   lcd_clrscreen
            ldaa  #nodata
            jsr   lcd_topmsg
            ldaa  #todisplay
            jsr   lcd_bottommsg
            rts


;This function will reoutput the current timestamp
timestamp_display:
            pshx                                ;save x register
            pshd                          ;save a and b registers

            lcd_settingmode
            ldaa  #$01
            jsr   lcd_write
            ldx   ts_current                 ;load the current timestamp to
point to


            lcd_writemode
```

```
            ldab 0,x
            jsr  lcd_output2digits        ;output the hours to the screen
            ldaa #$3A
            jsr  lcd_write                    ;output a :
            inx
            ldab 0,x
            jsr  lcd_output2digits        ;output the minutes to the screen
            ldaa #$3A
            jsr  lcd_write                    ;output a :
            inx
            ldab 0,x
            jsr  lcd_output2digits        ;output the seconds to the screen
            dex
            dex

            ldaa  ts_current_lit          ;load the current timestamp to point
at
            jsr   lcd_bottommsg           ;output the corresponding message on
the bottom LCD screen

            puld                                    ;restore a and b
            pulx                          ;restore x
            rts



;This function will update the display with one timestamp up from the current
one
timestamp_display_up:
            pshx                               ;save x register
            pshd                          ;save a and b registers

               lcd_settingmode
            ldaa  #$01
            jsr   lcd_write
            ldx   ts_current                  ;load the current timestamp to
point to
            inx                               ;advance 3 times (hrs, mins,
secs)
            inx
            inx
            inc  ts_current_lit               ;advance the literal position
            stx  ts_current                   ;store the new current pointer
            cpx  #ts_endbuffer             ;check to see if we are at the end
of the buffer
            bne  tdu_skip_reset           ;if not skip the next line
            movw #ts_buffer,ts_current    ;set the current position to the
front of the buffer
            movb #$01,ts_current_lit
            ldx   ts_current
tdu_skip_reset

            ldaa ts_current_lit
            cmpa ts_numstamps
            bgt  tdu_nodata
```

```
            lcd_writemode
            ldab 0,x
            jsr  lcd_output2digits        ;output the hours to the screen
            ldaa #$3A
            jsr  lcd_write                    ;output a :
            inx
            ldab 0,x
            jsr  lcd_output2digits        ;output the minutes to the screen
            ldaa #$3A
            jsr  lcd_write                    ;output a :
            inx
            ldab 0,x
            jsr  lcd_output2digits        ;output the seconds to the screen
            dex
            dex

            ldaa  ts_current_lit          ;load the current timestamp to point
at
            jsr   lcd_bottommsg           ;output the corresponding message on
the bottom LCD screen

            puld                                    ;restore a and b
            pulx                          ;restore x
            rts

tdu_nodata
            ldaa  #nodata
               jsr   lcd_topmsg
               ldaa  ts_current_lit
               jsr   lcd_bottommsg
               puld
               pulx
               rts

;This function will update the display with one timestamp down from the current
one
timestamp_display_down:
            pshx                               ;save x register
            pshd                          ;save a and b registers

               lcd_settingmode
            ldaa  #$01
            jsr   lcd_write
            ldx   ts_current                  ;load the current timestamp to
point to
            dex                               ;advance 3 times (hrs, mins,
secs)
            dex
            dex
            dec   ts_current_lit              ;advance the literal position
            stx   ts_current                  ;store the new current pointer
            cpx   #ts_bufferm1             ;check to see if we are at the end
of the buffer
            bne   tdd_skip_reset           ;if not skip the next line
            ldx   #ts_endbuffer           ;set the current position to the
front of the buffer
            dex
```

```
            dex
            dex
            movb  #$0A,ts_current_lit
            stx   ts_current
tdd_skip_reset

            ldaa ts_current_lit
            cmpa ts_numstamps
            bgt  tdd_nodata


            lcd_writemode
            ldab 0,x
            jsr  lcd_output2digits        ;output the hours to the screen
            ldaa #$3A
            jsr  lcd_write                    ;output a :
            inx
            ldab 0,x
            jsr  lcd_output2digits        ;output the minutes to the screen
            ldaa #$3A
            jsr  lcd_write                    ;output a :
            inx
            ldab 0,x
            jsr  lcd_output2digits        ;output the seconds to the screen
            dex
            dex

            ldaa  ts_current_lit          ;load the current timestamp to point
at
            jsr   lcd_bottommsg           ;output the corresponding message on
the bottom LCD screen

            puld                                  ;restore a and b
            pulx                          ;restore x
            rts

tdd_nodata
            ldaa  #nodata
               jsr   lcd_topmsg
               ldaa  ts_current_lit
               jsr   lcd_bottommsg
               puld
               pulx
               rts
            rts
;*************************************************************
;I^2C Initialization
;*************************************************************

iscinit:
; IIC Address Register (IBAD)
; Value: 11000000 (11000001 for reading)
;

            movb  #$D0,IBAD

; IIC Frequency Divide Register
```

```
; Value: 0x23 For setting the clock to 100kHz
;             and keeping the SDA hold time low

            movb  #$23,IBFD

; IIC Control Register
; Value: 10010000

               movb  #$90,IBCR

      rts


isc_read:
            bset  IBCR,mIBCR_MS_SL ; begins transfer of data (generates START
condition)
            jsr waitloop


            movb  #$C1,IBDR ; select slave address
            jsr   waitloop

            movb  #$11,IBDR ;selects register 11 on the camera
            bset  IBCR,#%00010000

            jsr waitloop


          ;  bclr  IBCR,mIBCR_MS_SL; ends transfer of data (generates STOP
condition)

               jsr waitloop


            rts
;*************************************************************
;Camera Initialization
;Prerequisite: I2C Module must be initialized
;*************************************************************

camerainit:


;;;;;;;;;BEGIN I2C COMMUNICATION
            jsr waitloop

;Setting camera registers:

;Resets the camera
            bset  IBCR,mIBCR_MS_SL ; begins transfer of data (generates START
condition)
            jsr waitloop


            movb  #$C0,IBDR ; select slave address
            jsr   waitloop
```

```
            movb  #$12,IBDR ;selects register 12 on the camera
            jsr waitloop

            movb  #$A4,IBDR ;writes A4 to register 12 on the camera
            jsr waitloop

            bclr  IBCR,mIBCR_MS_SL; ends transfer of data (generates STOP
condition)

           jsr waitloop

;White Pixel Ratio

            bset  IBCR,mIBCR_MS_SL ; begins transfer of data (generates START
condition)
            jsr waitloop


            movb  #$C0,IBDR ; select slave address
            jsr   waitloop

             movb  #$24,IBDR ;selects register 24 on the camera
            jsr waitloop

            movb  #$69,IBDR ;writes 64 to register 24 on the camera
            jsr waitloop

            bclr  IBCR,mIBCR_MS_SL; ends transfer of data (generates STOP
condition)

               jsr waitloop

;Dark Pixel Ratio

            bset  IBCR,mIBCR_MS_SL ; begins transfer of data (generates START
condition)
            jsr waitloop


            movb  #$C0,IBDR ; select slave address
            jsr   waitloop

             movb  #$25,IBDR ;selects register 25 on the camera
            jsr waitloop

            movb  #$79,IBDR ;writes 79 to register 25 on the camera
            jsr waitloop

            bclr  IBCR,mIBCR_MS_SL; ends transfer of data (generates STOP
condition)

               jsr waitloop
```

```
;3E - 2 clock divider

            bset  IBCR,mIBCR_MS_SL ; begins transfer of data (generates START
condition)

            movb  #$C0,IBDR ; select slave address
            jsr   waitloop

             movb  #$3E,IBDR ;selects register 3E on the camera
            jsr waitloop

            movb  #$80,IBDR ;writes 80 to register 3E on the camera (18)
            jsr waitloop

            bclr  IBCR,mIBCR_MS_SL; ends transfer of data (generates STOP
condition)

           jsr waitloop
;Address 0x11: Clock frequency Divider: 0x3F
;This sets reference signal polarities and clock prescaler.
;This will set our PCLK to 70KHz

            bset  IBCR,mIBCR_MS_SL ; begins transfer of data (generates START
condition)
            jsr waitloop


            movb  #$C0,IBDR ; select slave address
            jsr   waitloop

             movb  #$11,IBDR ;selects register 11 on the camera
            jsr waitloop

            movb  #$0a,IBDR ;writes 0a to register 11 on the camera
            jsr waitloop

            bclr  IBCR,mIBCR_MS_SL; ends transfer of data (generates STOP
condition)


;Address 0x14: Common Control C: 0x20: Sets QCIF Resolution
            bset  IBCR,mIBCR_MS_SL ; begins transfer of data (generates START
condition)
            jsr waitloop

            movb  #$C0,IBDR ; select slave address
            jsr waitloop

            movb  #$14,IBDR ;selects register 14 on the camera
            jsr waitloop

            movb  #$20,IBDR ;writes 20 to register 14 on the camera
            jsr waitloop

            bclr  IBCR,mIBCR_MS_SL ; ends transfer of data (generates STOP
condition)
```

```
            bset  IBCR,mIBCR_MS_SL ; begins transfer of data (generates START
condition)
            jsr waitloop

            movb  #$C0,IBDR ; select slave address
            jsr waitloop

            movb  #$39,IBDR ;selects register 0x39 on the camera
            jsr waitloop

            movb  #$40,IBDR ;writes 40 to register 0x39 on the camera
            jsr waitloop

            bclr  IBCR,mIBCR_MS_SL ; ends transfer of data (generates STOP
condition)


            rts


waitloop:                                       ;simple delay loop
            ldy #$FFFF
inwaitloop:
            idivs
            idivs
            idivs
            dey

            cpy   #$0000

            bne   inwaitloop

            rts


;*************************************************************
;ECT (PWM) Initialization
;*************************************************************

ectinit:

            movb   #$A8,TIOS    ;Set channels 7,5 and 3 to output compare
            movb   #$28,OC7M    ;Set channels 5 and 3 to change on 7 compare
            movb   #$28,OC7D    ;Set channels to output '1' on 7 compare
            movw   #$0753,TC3   ;Set pan motor to center point
            movw   #$0753,TC5   ;Set tilt motor to center point
            movw   #$7A12,TC7   ;Set pwm period to 20ms
            movb   #$80,TSCR1   ;Enable timer
            movw   #$4880,TCTL1 ;Clear channels 5 and 3 on compare
            movb   #$0B,TSCR2   ;Auto reset on 7 compare and prescale clock by
8
            movb   #$42,PACTL   ;Enable pulse accumulator A and turn on
interrupt
            bset   PAFLG,#$02   ;Clears the PA overflow interrupt flag

            rts
```

```
;*************************************************************
;Calibration
;*************************************************************

calibrate:
BEGIN_CALIBRATION:

BEGIN_SET_CAL_IMG:
        LDAA #$10 ; load in the index for the set cal img message
        JSR lcd_topmsg ; display the message on the lcd, "Set Cal Img", "Done?"
        LDAA #$11 ; load in the index for the set cal img message
        JSR lcd_bottommsg ; display the message on the lcd, "Set Cal Img",
"Done?"

CAL_PB_POLL_2:
        LDAA PTH ; check value on the okay pin
        ANDA #$02
        BEQ CAL_GET_REF_IMG ; okay PB pressed, move on to getting the reference
image
        LDAA PTH ; check the cancel button
        ANDA #$01
       BEQ BEGIN_CALIBRATION ; cancel button pressed, go back one step
       BRA CAL_PB_POLL_2  ; keep checking until button is pressed


CAL_GET_REF_IMG:
        MOVB #$01, CAL_REF_IMG ; store 1 in calrefimg to tell it you are in
calibration
        CLI ; enable interrupts for pclk/vync so you can get an image
        MOVB #$02, PIEJ ; enable interrupts from port j (vsync)
WAIT_FOR_SPECIAL_FIND_OBJECTS:
        LDAA CAL_REF_IMG ; load in the var, 1 = in cal, 0 = done/not in cal
        BNE WAIT_FOR_SPECIAL_FIND_OBJECTS ; if its still a 1, wait for it to
finish
        SEI ; it sets calrefimg to 0 when it's done, so now we have our data

CHECK_REF_IMG_FOR_ERRORS:

CAL_COL_OBJ1:
        LDAA COL_OBJ1 ; load col center of 1st value
        CMPA #COLS13 ; compare to 1/3 width to see if its in the right section
        BLO CAL_ROW_OBJ1 ; if it is, check row value
        LDAA #$12  ; not in correct section, display error to user
        JSR lcd_topmsg ; display the message on the lcd, "Move Obj 1 L",
"Done?"
        LDAA #$11  ; not in correct section, display error to user
        JSR lcd_bottommsg ; display the message on the lcd, "Move Obj 1 L",
"Done?"
        BRA CAL_PB_POLL_2 ; sends it back to take new ref frame and start over

CAL_ROW_OBJ1:
        LDAA ROW_OBJ1 ; load row center of 1st value
        CMPA #ROWS13 ; compare to 1/3 height to see if its in the right section
        BLO CAL_COL_OBJ2_GT ; if it is, check next object
        LDAA #$13  ; not in correct section, display error to user
```

```
        JSR lcd_topmsg ; display the message on the lcd, "Move Obj 1 U",
"Done?"
        LDAA #$11  ; not in correct section, display error to user
        JSR lcd_bottommsg ; display the message on the lcd, "Move Obj 1 U",
"Done?"
        BRA CAL_PB_POLL_2 ; sends it back to take new ref frame and start over

CAL_COL_OBJ2_GT:
        LDAA COL_OBJ2 ; load col center of 2nd value
        CMPA #COLS13 ; compare to 1/3 width to see if its in the right section
        BHI CAL_COL_OBJ2_LT ; if >1/3, move on to make sure its < 2/3
        LDAA #$14  ; not in correct section, display error to user
        JSR lcd_topmsg ; display the message on the lcd, "Move Obj 2 R",
"Done?"
        LDAA #$11  ; not in correct section, display error to user
        JSR lcd_bottommsg ; display the message on the lcd, "Move Obj 2 R",
"Done?"
        BRA CAL_PB_POLL_2 ; sends it back to take new ref frame and start over

CAL_COL_OBJ2_LT:
        LDAA COL_OBJ2 ; load col center of 2nd value
        CMPA #COLS23 ; compare to 2/3 width to see if its in the right section
        BLO CAL_ROW_OBJ2_GT ; if <2/3, move on to rows
        LDAA #$15  ; not in correct section, display error to user
        JSR lcd_topmsg ; display the message on the lcd, "Move Obj 2 L",
"Done?"
        LDAA #$11  ; not in correct section, display error to user
        JSR lcd_bottommsg ; display the message on the lcd, "Move Obj 2 L",
"Done?"
        BRA CAL_PB_POLL_2 ; sends it back to take new ref frame and start over

CAL_ROW_OBJ2_GT:
        LDAA ROW_OBJ2 ; load row center of 2nd value
        CMPA #ROWS13 ; compare to 1/3 height to see if its in the right section
        BHI CAL_ROW_OBJ2_LT ; if >1/3, move on to make sure its < 2/3
        LDAA #$16  ; not in correct section, display error to user
        JSR lcd_topmsg ; display the message on the lcd, "Move Obj 2 D",
"Done?"
        LDAA #$11  ; not in correct section, display error to user
        JSR lcd_bottommsg ; display the message on the lcd, "Move Obj 2 D",
"Done?"
        LBRA CAL_PB_POLL_2 ; sends it back to take new ref frame and start over

CAL_ROW_OBJ2_LT:
        LDAA ROW_OBJ2 ; load row center of 2nd value
        CMPA #ROWS23 ; compare to 2/3 height to see if its in the right section
        BLO CAL_COL_OBJ3 ; if <2/3, move on to object 3
        LDAA #$17  ; not in correct section, display error to user
        JSR lcd_topmsg ; display the message on the lcd, "Move Obj 2 U",
"Done?"
        LDAA #$11  ; not in correct section, display error to user
        JSR lcd_bottommsg ; display the message on the lcd, "Move Obj 2 U",
"Done?"
        LBRA CAL_PB_POLL_2 ; sends it back to take new ref frame and start over

CAL_COL_OBJ3:
        LDAA COL_OBJ3 ; load col center of 3rd value
```

```
        CMPA #COLS23 ; compare to 2/3 width to see if its in the right section
        BHI CAL_ROW_OBJ3 ; if it is, check row value
        LDAA #$18  ; not in correct section, display error to user
        JSR lcd_topmsg ; display the message on the lcd, "Move Obj 3 R",
"Done?"
        LDAA #$11  ; not in correct section, display error to user
        JSR lcd_bottommsg ; display the message on the lcd, "Move Obj 3 R",
"Done?"
        LBRA CAL_PB_POLL_2 ; sends it back to take new ref frame and start over

CAL_ROW_OBJ3:
        LDAA ROW_OBJ3 ; load row center of 3rd value
        CMPA #ROWS23 ; compare to 2/3 height to see if its in the right section
        BHI INITIAL_AIM_COL_MOTOR ; if it is, done checking objects, move on
        LDAA #$19  ; not in correct section, display error to user
        JSR lcd_topmsg ; display the message on the lcd, "Move Obj 3 D",
"Done?"
        LDAA #$11  ; not in correct section, display error to user
        JSR lcd_bottommsg ; display the message on the lcd, "Move Obj 3 D",
"Done?"
        LBRA CAL_PB_POLL_2 ; sends it back to take new ref frame and start over

INITIAL_AIM_COL_MOTOR:
        LDD ATD1DR0H ; do once before displaying on lcd to avoid both motors
drawing current at same time
        LSLD ; multiply pot value by 2 since it's only 10 bit
        ADDD #PWM_MINV ; add the min offset
        CPD #PWM_MAXV ; compare to max
        BLT CAL_COL_POT_OKAY0 ; value okay, aim
        LDD #PWM_MAXV ; value not okay, set to the max
        CAL_COL_POT_OKAY0:
        STD TC3 ; store the offset + 2*pot value in pan motor aim

        BSET PTH, #$04 ; turn on laser pointer

CAL_AIM_OBJ1:
        LDAA #$1A ; load index of lcd message
        JSR lcd_topmsg ; display message to user "AIM LASER AT", "TOP LEFT OBJ"
        LDAA #$1B ; load index of lcd message
        JSR lcd_bottommsg ; display message to user "AIM LASER AT", "TOP LEFT
OBJ"

CAL_AIM_COL_POT1:
        LDD ATD1DR0H ; load value off pan pot
        LSLD ; multiply pot value by 2 since it's only 10 bit
        ADDD #PWM_MINV ; add the min offset
        CPD #PWM_MAXV ; compare to max
        BLT CAL_COL_POT_OKAY1 ; value okay, aim
        LDD #PWM_MAXV ; value not okay, set to the max
CAL_COL_POT_OKAY1:
      STD TEMP_PRODUCT     ; checking for noise on atd
      SUBD TC3             ; dont change motors unless the atd value
        CPD #$0007                 ; has changed by more than 7 out of 10 bit
max value
        BLS CAL_AIM_ROW_POT1
        CPD #$FFF8
        BHS CAL_AIM_ROW_POT1
```

```
        MOVW TEMP_PRODUCT, TC3 ; store the offset + 2*pot value in pan motor
aim

CAL_AIM_ROW_POT1:
        LDD ATD0DR0H ; load value off tilt pot
        LSLD ; multiply pot value by 2 since it's only 10 bit
        ADDD #PWM_MINV ; add the min offset
        CPD #PWM_MAXV ; compare to max
        BLT CAL_ROW_POT_OKAY1 ; value okay, aim
        LDD #PWM_MAXV ; value not okay, set to the max
CAL_ROW_POT_OKAY1:
        STD TEMP_PRODUCT
       SUBD TC5                    ; atd noise cancelling
        CPD #$0007
        BLS CAL_PB_POLL_3
        CPD #$FFF8
        BHS CAL_PB_POLL_3
        MOVW TEMP_PRODUCT, TC5 ; store the offset + 2*pot value in tilt motor
aim

CAL_PB_POLL_3:
       LDAA PTH ; check value on the okay pin
        ANDA #$02
        BEQ CAL_STORE_OBJ1_VALUES ; okay PB pressed, move on
        LDAA PTH ; check the cancel button
        ANDA #$01
       LBEQ BEGIN_CALIBRATION ; cancel button pressed, go back one step
        BRA CAL_AIM_COL_POT1 ; reset the aim values

CAL_STORE_OBJ1_VALUES:
        MOVW TC3,COL_PWM1 ; saving col pwm value for obj1
        MOVW TC5,ROW_PWM1 ; saving row pwm value for obj1
       jsr   lcd_polldelay

CAL_AIM_OBJ2:
        LDAA #$1A ; load index of lcd message
        JSR lcd_topmsg ; display message to user "AIM LASER AT", "MIDDLE OBJ"
        LDAA #$1C ; load index of lcd message
        JSR lcd_bottommsg ; display message to user "AIM LASER AT", "MIDDLE
OBJ"
       JSR lcd_polldelay
       JSR lcd_polldelay
       JSR lcd_polldelay
       JSR lcd_polldelay                  ; debouncing delay
       JSR lcd_polldelay
       JSR lcd_polldelay
       JSR lcd_polldelay
       JSR lcd_polldelay
       JSR lcd_polldelay
       JSR lcd_polldelay

CAL_AIM_COL_POT2:
        LDD ATD1DR0H ; load value off pan pot
        LSLD ; multiply pot value by 2 since it's only 10 bit
        ADDD #PWM_MINV ; add the min offset
        CPD #PWM_MAXV ; compare to max
       BLT CAL_COL_POT_OKAY2 ; value okay, aim
```

```
        LDD #PWM_MAXV ; value not okay, set to the max
CAL_COL_POT_OKAY2:
        STD TEMP_PRODUCT
       SUBD TC3
        CPD #$0007                      ; atd noise cancelling
        BLS CAL_AIM_ROW_POT2
        CPD #$FFF8
        BHS CAL_AIM_ROW_POT2
        MOVW TEMP_PRODUCT, TC3 ; store the offset + 2*pot value in pan motor
aim

CAL_AIM_ROW_POT2:
        LDD ATD0DR0H ; load value off tilt pot
        LSLD ; multiply pot value by 2 since it's only 10 bit
        ADDD #PWM_MINV ; add the min offset
        CPD #PWM_MAXV ; compare to max
        BLT CAL_ROW_POT_OKAY2 ; value okay, aim
        LDD #PWM_MAXV ; value not okay, set to the max
CAL_ROW_POT_OKAY2:
        STD TEMP_PRODUCT
       SUBD TC5
        CPD #$0007                   ; atd noise cancelling
        BLS CAL_PB_POLL_4
        CPD #$FFF8
        BHS CAL_PB_POLL_4
        MOVW TEMP_PRODUCT, TC5 ; store the offset + 2*pot value in tilt motor
aim

CAL_PB_POLL_4:
        LDAA PTH ; check value on the okay pin
        ANDA #$02
        BEQ CAL_STORE_OBJ2_VALUES ; okay PB pressed, move on
        LDAA PTH ; check the cancel button
        ANDA #$01
      LBEQ CAL_AIM_OBJ1 ; cancel button pressed, go back one step
        BRA CAL_AIM_COL_POT2 ; reset the aim values

CAL_STORE_OBJ2_VALUES:
        MOVW TC3,COL_PWM2 ; saving col pwm value for obj2
        MOVW TC5,ROW_PWM2 ; saving row pwm value for obj2

CAL_AIM_OBJ3:
        LDAA #$1A ; load index of lcd message
        JSR lcd_topmsg ; display message to user "AIM LASER AT", "BOTRIGHT OBJ"
        LDAA #$1D ; load index of lcd message
        JSR lcd_bottommsg ; display message to user "AIM LASER AT", "BOTRIGHT
OBJ"
      JSR lcd_polldelay
      JSR lcd_polldelay
      JSR lcd_polldelay
      JSR lcd_polldelay
      JSR lcd_polldelay                ; DEBOUNCING DELAY
      JSR lcd_polldelay
      JSR lcd_polldelay
      JSR lcd_polldelay
      JSR lcd_polldelay
      JSR lcd_polldelay
```

```
CAL_AIM_COL_POT3:
        LDD ATD1DR0H ; load value off pan pot
        LSLD ; multiply pot value by 2 since it's only 10 bit
        ADDD #PWM_MINV ; add the min offset
        CPD #PWM_MAXV ; compare to max
        BLT CAL_COL_POT_OKAY3 ; value okay, aim
        LDD #PWM_MAXV ; value not okay, set to the max
CAL_COL_POT_OKAY3:
        STD TEMP_PRODUCT
       SUBD TC3
        CPD #$0007                      ; atd noise cancelling
        BLS CAL_AIM_ROW_POT3
        CPD #$FFF8
        BHS CAL_AIM_ROW_POT3
        MOVW TEMP_PRODUCT, TC3 ; store the offset + 2*pot value in pan motor
aim

CAL_AIM_ROW_POT3:
        LDD ATD0DR0H ; load value off tilt pot
        LSLD ; multiply pot value by 2 since it's only 10 bit
        ADDD #PWM_MINV ; add the min offset
        CPD #PWM_MAXV ; compare to max
        BLT CAL_ROW_POT_OKAY3 ; value okay, aim
        LDD #PWM_MAXV ; value not okay, set to the max
CAL_ROW_POT_OKAY3:
        STD TEMP_PRODUCT
       SUBD TC5
        CPD #$0007                     ; atd noise cancelling
        BLS CAL_PB_POLL_5
        CPD #$FFF8
        BHS CAL_PB_POLL_5
        MOVW TEMP_PRODUCT, TC5 ; store the offset + 2*pot value in tilt motor
aim

CAL_PB_POLL_5:
        LDAA PTH ; check value on the okay pin
        ANDA #$02
        BEQ CAL_STORE_OBJ3_VALUES ; okay PB pressed, move on
        LDAA PTH ; check the cancel button
        ANDA #$01
       LBEQ CAL_AIM_OBJ2 ; cancel button pressed, go back one step
        BRA CAL_AIM_COL_POT3 ; reset the aim values

CAL_STORE_OBJ3_VALUES:
        MOVW TC3,COL_PWM3 ; saving col pwm value for obj3
        MOVW TC5,ROW_PWM3 ; saving row pwm value for obj3

CAL_CALCULATIONS:
        BCLR PTH, #$04 ; turn off laser pointer
        MOVW COL_PWM2,TC3 ; recenter motors to aim laser at middle of image
        MOVW COL_PWM2,TC5 ; both col and row

FIND_COL_SLOPE1:
        LDAB COL_OBJ3 ; find this colslope[1] = (pwmcol[2] -
pwmcol[3])/(colobj[3] - colobj[2])
        SUBB COL_OBJ2
```

```
        LDAA #$00 ; D = A:B = 00:(colobj[3] - colobj[2]) = (colobj[3] -
colobj[2])
        TFR D,X ; put (colobj[3] - colobj[2]) in X
        LDD COL_PWM2
        SUBD COL_PWM3 ; (pwmcol[2] - pwmcol[3]) in D
        LSLD
        LSLD            ; multiply slope value by 16 ($10) before dividing to
reduce rounding errors
        LSLD            ; when multiplying slope for aiming in find center
routine, it divides by 16 ($10)
        LSLD
        IDIV ; D/X --> X
        STX COL_SLOPE1 ; save the slope

FIND_COL_SLOPE2:
        LDAB COL_OBJ2 ; find this colslope[2] = (pwmcol[1] -
pwmcol[2])/(colobj[2] - colobj[1])
        SUBB COL_OBJ1
        LDAA #$00 ; D = A:B = 00:(colobj[2] - colobj[1]) = (colobj[2] -
colobj[1])
        TFR D,X ; put (colobj[2] - colobj[1]) in X

        LDD COL_PWM1
        SUBD COL_PWM2 ; (pwmcol[1] - pwmcol[2]) in D
        LSLD
        LSLD              ; multiply slope value by 16 ($10) before dividing to
reduce rounding errors
        LSLD              ; when multiplying slope for aiming in find center
routine, it divides by 16 ($10)
        LSLD
        IDIV ; D/X --> X
        STX COL_SLOPE2 ; save the slope

FIND_COL_SLOPE3:
        LDAB COL_OBJ3 ; find this colslope[3] = (pwmcol[1] -
pwmcol[3])/(colobj[3] - colobj[1])
        SUBB COL_OBJ1
        LDAA #$00 ; D = A:B = 00:(colobj[3] - colobj[1]) = (colobj[3] -
colobj[1])
        TFR D,X ; put (colobj[3] - colobj[1]) in X
        LDD COL_PWM1
        SUBD COL_PWM3 ; (pwmcol[1] - pwmcol[3]) in D
        LSLD
        LSLD              ; multiply slope value by 16 ($10) before dividing to
reduce rounding errors
        LSLD              ; when multiplying slope for aiming in find center
routine, it divides by 16 ($10)
        LSLD
        IDIV ; D/X --> X
        STX COL_SLOPE3 ; save the slope

FIND_COL_SLOPE_AVG:
        LDD COL_SLOPE1 ; load the slopes
        ADDD COL_SLOPE2 ; find the sum
        ADDD COL_SLOPE3
        LDX #$0003 ; load 3 in x
        IDIV ; D/X => X
```

```
        TFR X,D           ; actually storing 16*slope ($10*slope), have to
divide by 16 when using it
        STD COL_SLOPE_AVG ; avg slope in x, store in colslopeavg

FIND_ROW_SLOPE1:
        LDAB ROW_OBJ3 ; find this rowslope[1] = (pwmrow[3] -
pwmrow[2])/(rowobj[3] - rowobj[2])
        SUBB ROW_OBJ2
        LDAA #$00 ; D = A:B = 00:(rowobj[3] - rowobj[2]) = (rowobj[3] -
rowobj[2])
        TFR D,X ; put (rowobj[3] - rowobj[2]) in X
        LDD ROW_PWM3
        SUBD ROW_PWM2 ; (pwmrow[3] - pwmrow[2]) in D
        LSLD
        LSLD              ; multiply slope value by 16 ($10) before dividing to
reduce rounding errors
        LSLD              ; when multiplying slope for aiming in find center
routine, it divides by 16 ($10)
        LSLD
        IDIV ; D/X --> X
        STX ROW_SLOPE1 ; save the slope

FIND_ROW_SLOPE2:
        LDAB ROW_OBJ2 ; find this rowslope[2] = (pwmrow[2] -
pwmrow[1])/(rowobj[2] - rowobj[1])
        SUBB ROW_OBJ1
        LDAA #$00 ; D = A:B = 00:(rowobj[2] - rowobj[1]) = (rowobj[2] -
rowobj[1])
        TFR D,X ; put (rowobj[2] - rowobj[1]) in X
        LDD ROW_PWM2
        SUBD ROW_PWM1 ; (pwmrow[2] - pwmrow[1]) in D
        LSLD
        LSLD              ; multiply slope value by 16 ($10) before dividing to
reduce rounding errors
        LSLD              ; when multiplying slope for aiming in find center
routine, it divides by 16 ($10)
        LSLD
        IDIV ; D/X --> X
        STX ROW_SLOPE2 ; save the slope

FIND_ROW_SLOPE3:
        LDAB ROW_OBJ3 ; find this rowslope[3] = (pwmrow[3] -
pwmrow[1])/(rowobj[3] - rowobj[1])
        SUBB ROW_OBJ1
        LDAA #$00 ; D = A:B = 00:(rowobj[3] - rowobj[1]) = (rowobj[3] -
rowobj[1])
        TFR D,X ; put (rowobj[3] - rowobj[1]) in X
        LDD ROW_PWM3
        SUBD ROW_PWM1 ; (pwmrow[3] - pwmrow[1]) in D
        LSLD
        LSLD              ; multiply slope value by 16 ($10) before dividing to
reduce rounding errors
        LSLD              ; when multiplying slope for aiming in find center
routine, it divides by 16 ($10)
        LSLD
        IDIV ; D/X --> X
        STX ROW_SLOPE3 ; save the slope
```

```
FIND_ROW_SLOPE_AVG:
        LDD ROW_SLOPE1 ; load the slopes
        ADDD ROW_SLOPE2 ; find the sum
        ADDD ROW_SLOPE3
        LDX #$0003 ; load 3 in x
        IDIV ; D/X => X
        TFR X,D     ; actually storing 16*slope ($10*slope), have to divide by
16 when using it
        STD ROW_SLOPE_AVG ; avg slope in x, store in rowslopeavg

FIND_COL_AIM_OFFSET:
        LDAB COL_OBJ1 ; load center value of object 1
        LDAA #$00 ; put 0 in A because EMUL uses D*Y
        LDY COL_SLOPE_AVG ; load slope to multiply by the center of obj1
        EMUL ; D*Y=>Y:D, is the mx part of mx + y = b, Y reg should be 0, only
care about D
        LDX #$10           ; dividing by $10 to cancel out the slope modifier
        EDIV
        TFR Y,D
        BRA COL_AIM_OKAY ; if 0, okay, move on

CAL_PB_POLL_6:
        LDAA PTH ; check value on the okay pin
        ANDA #$02
        LBEQ BEGIN_CALIBRATION ; okay PB pressed, start over and try again
        BRA CAL_PB_POLL_6 ; reset the aim values

COL_AIM_OKAY:
        ADDD COL_PWM1 ; adds the pwm value to aim at obj 1
        STD COL_AIM_OFFSET ; this is the offset for aiming the motor all the
way at the left side of the image
        CPD #PWM_MAXV ; max offset
        BLT CHECK_COL_OFFSET ; no error, continue
        LDAA #$20 ; load number for error message
        JSR lcd_topmsg ; display message "COL OFFSET", "TOO HIGH"
        LDAA #$21 ; load number for error message
        JSR lcd_bottommsg ; display message "COL OFFSET", "TOO HIGH"

CAL_PB_POLL_7:
        LDAA PTH ; check value on the okay pin
        ANDA #$02
        LBEQ BEGIN_CALIBRATION ; okay PB pressed, start over and try again
        BRA CAL_PB_POLL_7 ; reset the aim values

CHECK_COL_OFFSET:
        CPD #PWM_MINV ; min offset
        BGT FIND_ROW_AIM_OFFSET ; no error, continue
        LDAA #$20 ; load number for error message
        JSR lcd_topmsg ; display message "COL OFFSET", "TOO LOW"
        LDAA #$22 ; load number for error message
        JSR lcd_bottommsg ; display message "COL OFFSET", "TOO LOW"

FIND_ROW_AIM_OFFSET:
        LDAB ROW_OBJ1 ; load center value of object 1
        LDAA #$00 ; put 0 in A so you can use D
        LDY ROW_SLOPE_AVG ; load slope to multiply by the center of obj1
```

```
        EMUL ; D*Y=>Y:D, is the mx part of y - mx = b, Y reg should be 0, only
care about D
        LDX #$10          ; dividing by $10 to cancel out the slope modifier
        EDIV
        TFR Y,D
        BRA ROW_AIM_OKAY ; if 0, okay, move on

ROW_AIM_OKAY:
        STD ROW_AIM_OFFSET ; temp store in the offset so you can 16bit sub
        LDD ROW_PWM1 ; loads the pwm value to aim at obj 1
        SUBD ROW_AIM_OFFSET ; does the y-mx calc, b is now in the D register
        STD ROW_AIM_OFFSET ; this is the offset for aiming the motor all the
way at the top side of the image
        CPD #PWM_MAXV ; max offset
        BLT CHECK_ROW_OFFSET ; no error, continue
        LDAA #$24 ; load number for error message
        JSR lcd_topmsg ; display message "ROW OFFSET", "TOO HIGH"
        LDAA #$21 ; load number for error message
        JSR lcd_bottommsg ; display message "ROW OFFSET", "TOO HIGH"

CAL_PB_POLL_10:
        LDAA PTH ; check value on the okay pin
        ANDA #$02
        LBEQ BEGIN_CALIBRATION ; okay PB pressed, start over and try again
        BRA CAL_PB_POLL_10 ; reset the aim values

CHECK_ROW_OFFSET:
        CPD #PWM_MINV ; min offset
        BGT FINISH_CALIBRATION ; no error, continue
        LDAA #$24 ; load number for error message
        JSR lcd_topmsg ; display message "ROW OFFSET", "TOO LOW"
        LDAA #$22 ; load number for error message
        JSR lcd_bottommsg ; display message "ROW OFFSET", "TOO LOW"

CAL_PB_POLL_11:
        LDAA PTH ; check value on the okay pin
        ANDA #$02
        LBEQ BEGIN_CALIBRATION ; okay PB pressed, start over and try again
        BRA CAL_PB_POLL_11 ; reset the aim values

FINISH_CALIBRATION:
        LDAA #$25 ; load number for lcd display
        JSR lcd_topmsg ; display message "CALIBRATION", "COMPLETE!"
        LDAA #$26 ; load number for lcd display
        JSR lcd_bottommsg ; display message "CALIBRATION", "COMPLETE!"
      JSR lcd_polldelay
      JSR lcd_polldelay
      JSR lcd_polldelay          ; delay to display calibration complete
message
      JSR lcd_polldelay          ; and allow user to move away from camera
before it takes a ref img
      JSR lcd_polldelay
      JSR lcd_polldelay
      JSR lcd_polldelay
      JSR lcd_polldelay
      JSR lcd_polldelay
      JSR lcd_polldelay
```

```
        RTS ; return from sub routine, calibration complete


;***************************************************************
;Threshhold Subroutine
;***************************************************************

threshhold:
            cli                             ;allow to be interrupted
            ldy   #TROW_START               ;load starting temp address
            ldx   #min_col_addr             ;load starting column address
            ldab  #$00                      ;load 0 into b
  th_loop:  ldaa  1,y+                      ;load next pixel value from temp
address
            cmpa  THLD                      ;compare to threshhold
            bhi   L_PASS                    ;if greater, branch away
            inx                             ;increment x
            cpx   #max_col_addr             ;check if done
            bne   th_loop                   ;if not done, continue loop
  th_done:  ldy   IROW                      ;load current row address
            stab  1,y+                      ;store row data
            cpy   #max_row_addr             ;check if image done
            beq   L_IMG_DONE                ;if done, branch away
            sty   IROW                      ;store next row address
            movw  #TROW_START,TEMPROW       ;reset temprow address for next row
            rts                             ;exit sub

  L_PASS:
            incb                            ;increment b (row data)
            inc   1,x+                      ;increment col data and post inc x
            cpx   #max_col_addr             ;check if done
            bne   th_loop                   ;if not done, continue loop
            bra   th_done                   ;if done, branch to th_done

  L_IMG_DONE:
            movb  #$03,PIEH                 ;turn off href interrupts

            jsr   find_target               ;jump to find_center routine

            rts                             ;exit sub



;***************************************************************
;****************************ISRs*******************************
;***************************************************************

;***************************************************************
;Vsync ISR
;***************************************************************

isr_pclkvsync:

            ldaa  WANTFRAME                 ;check if we want frame
```

```
            ;adda  #$40
            coma
            staa  WANTFRAME               ;store wantframe variable
            bne   L_NOFRAME               ;branch if don't want frame

            movw  #min_row_addr,IROW      ;reset the row address
            movw  #IMGADDR_START,IMGADDR  ;reset the image address
            movw  #TROW_START,TEMPROW     ;reset the temp row address
            clr   WANTROW                 ;turn on first row
            movb  #$40,PIEH               ;turn back on hclk interrupts
            bset  PIFJ,#$02               ;clear interrupt flags
            cli                           ;turn on interrupts
            rti                                     ;exit isr

  L_NOFRAME:
            movb  #$00,PIEH               ;turn off href interrupts
            bset PIFJ,#$02
            cli                           ;turn on interrupts
            rti                               ;exit isr


;***************************************************************
;Push Button ISR
;***************************************************************

isr_pshbtns:

      brset PIFH,#$40,isr_href            ;branch if only href interrupt
      ;This ISR exists to wake up the main loop and check the buttons
    ;  bset PIFH,#$03

      cli
      rti



;***************************************************************
;Href ISR
;***************************************************************


  isr_href:
            ldaa  WANTROW                 ;check if we want this row

            coma                          ;want every other row
            staa  WANTROW                 ;store wantrow variable
            beq   L_norow                 ;branch if we don't want the row
            bset  PIFH,#$40               ;clear href interrupt flag

              ldx   IMGADDR                   ;load next pixel address
            ldy   TEMPROW                     ;load next temp address
            ldab  REFIMG                      ;check if we want reference image
            bne   L_REF_IMG                   ;branch if reference image
  L_loop6:  brclr PTJ,#$01,L_loop6        ;loop while pclk is low
  L_loop3:  ldaa  PTP                         ;load pixel data from bus
            suba  1,x+                        ;subtract from stored pixel
            bcc   L_POS_SUB                   ;branch if positive
```

```
            nega                                    ;take absolute value

  L_POS_SUB:
            staa  1,y+                      ;store difference in temp
location
            cpy   #TROW_END                 ;check if end of row
            beq L_ROW_DONE                  ;branch away if row complete
  L_loop1:  brset PTJ,#$01,L_loop1          ;wait until pclk goes low
  L_loop2:  brclr PTJ,#$01,L_loop2          ;wait until pclk goes high
            bra   L_loop3                   ;branch back to get data

  L_ROW_DONE:
            stx   IMGADDR                   ;save next pixel address
            jsr   threshhold              ;run threshholder code
            rti                           ;exit isr

  L_norow:
            bset  PIFH,#$40               ;clear href interrupt flag
            cli                           ;enable interrupts
            rti                           ;exit isr

  L_REF_IMG:
  L_loop7:  brclr PTJ,#$01,L_loop7          ;wait until pclk goes high
  L_loop8:  ldaa  PTP                       ;get pixel data from bus
            staa  1,x+                      ;store pixel in next ref image
space
            iny                             ;incrememnt spot in current row
            cpy   #TROW_END                 ;check if row finished
            beq   L_REFROW_DONE             ;branch if row complete
  L_loop4:  brset PTJ,#$01,L_loop4          ;wait until pclk goes low
  L_loop5:  brclr PTJ,#$01,L_loop5          ;wait until pclk goes back high
            bra   L_loop8                   ;loop back to get next pixel

  L_REFROW_DONE:
            stx   IMGADDR                   ;store next pixel location
            ldx   IROW                      ;load row index
            inx                             ;increment row index
            cpx   #max_row_addr             ;check if that was the last row
            beq   L_REF_DONE                ;branch if image complete
            stx   IROW                      ;store row index
            movw  #TROW_START,TEMPROW     ;reload temporary row start address
            cli                             ;enable interrupts
            rti                             ;exit isr

  L_REF_DONE:
            movb  #$03,PIEH                 ;turn off href interrupts until
next frame
            clr REFIMG                  ;clear reference image flag
            cli                             ;enable interrupts
            rti                             ;exit isr
```

```
;*************************************************************
;Motion detection Subroutine
;*************************************************************

find_target:

      MOVB #$00,ROW_DATA_ADDR_START ; first row value always messed up due to
edges
      MOVB #$00,$08AF                 ; last col value always messed up due to
edges
COL_BEGIN_FIND_CENTER:
       LDX #COL_DATA_ADDR_END ; load the address of the end of column data
       MOVB COL_DATA_ADDR_END, MAXCOLV ; store first(last) column value as
maxcolvalue

COL_FIND_MAX:
       CPX #COL_DATA_ADDR_START ; check to see if you are at the beginning of
the column data
       BLS CHECK_MAXCOLV_THRESHHOLD ; if still >, keep checking values, else
go to find object
       LDAA MAXCOLV ; load the max column value into the A register
       SUBA 1,X- ; do the subtraction and post dec X
       BHI COL_FIND_MAX ; if not a new max, branch back to the check loop
       MOVB 1,X,MAXCOLV ; move the new max into maxcolv
       BRA COL_FIND_MAX ; next column

CHECK_MAXCOLV_THRESHHOLD:
      LDAA MAXCOLV ; load maxcolv
      CMPA #MAXCOLV_THRESHHOLD ; check to see if maxcolv is high enough for
motion
      BHS COL_BEGIN_FIND_OBJECTS ; above threshold, motion detected
      MOVB #$00, MOTION_DETECTED ; no motion, store 0
      LBRA END_FIND_OBJECTS ; no motion, finish sub

COL_BEGIN_FIND_OBJECTS:
       INC MOTION_DETECTED ; variable for motion detected, motion is detected
       LDX #COL_DATA_ADDR_END ; load the address of the end of column data
       ; maxcolv still in A register
       LSRA ; divide max column value by 2, this threshhold is used for
finding important columns
       STAA MAXCOLV ; store this new value in maxcolv since we dont care about
maxcolv anymore
       MOVB #$00,OBJECT_EXIST ; initialize object exist to 0, means not
currently in object
       MOVB #NUM_OF_COLS,END_OF_OBJECT ; initialize end of object as the last
col
       MOVB #NUM_OF_COLS,COL_INDEX ; keeps track of current column index
       INC COL_INDEX ; inc once because it decs at beginning of find object
       MOVB #$00,MAX_OBJECT_WIDTH ; widest object is 0 by default

CHECK_COL_CAL_REF_IMG:
       LDAA CAL_REF_IMG ; check to see if its a cal ref img or real image
       LBEQ COL_FIND_OBJECTS ; if 0, normal image, else special image
       LDX #COL_DATA_ADDR_START ; load in addr of first col data
       MOVB #$00, COL_INDEX ; start at col 0
       MOVB #$00, MOTION_DETECTED ; no timestamping in calibration ref check
```

```
CFO_COL_BEGIN:
        MOVB #$00, OBJECT_EXIST ; object doesn't exist to begin with
        MOVB #$00, MAX_OBJECT_WIDTH ; reset widest object to 0

CFO_COL_LOOP:
        INC COL_INDEX ; inc col index variable to keep track, starts at 0
        LDAA COL_INDEX ; load col index
        CMPA #COLS13 ; check to see if you are on left
        BEQ CFO_COL_END_FIND_OBJECTS ; end area 1
        CMPA #COLS23 ; check to see if you are in the middle
        BEQ CFO_COL_END_FIND_OBJECTS ; end area 2
        CMPA #NUM_OF_COLS ; check to see if you are on right
        BEQ CFO_COL_END_FIND_OBJECTS ; end area 3

        LDAA #CAL_THOLD ; load the cutoff threshhold into the A register
        CMPA 1,X+ ; check to see if it is an object (above threshhold), post
inc x
        BHI CFO_COL_BELOW_THRESHHOLD ; if maxcol > current value, no object

CFO_COL_OBJECT_FOUND:
        LDAB OBJECT_EXIST ; load the value to see if you are currently in an
object
        BNE CFO_COL_LOOP; if non zero, object already existed, do nothing

CFO_COL_NEW_OBJECT:
        MOVB #$01,OBJECT_EXIST ; object just started, set object_exists = 1
        MOVB COL_INDEX,END_OF_OBJECT ; store col_index as the end(beginning) of
a new object
        BRA CFO_COL_LOOP ; back to find objects loop

CFO_COL_BELOW_THRESHHOLD:
        LDAB OBJECT_EXIST ; load the value to see if you are currently in an
object
        BEQ CFO_COL_LOOP ; if zero, no object, not in object, do nothing.
return to find objects for next

CFO_COL_OBJECT_END:
      MOVB #$00,OBJECT_EXIST  ; no longer in an object
        LDAB COL_INDEX ; load the end(beginning) of object
        SUBB END_OF_OBJECT ; find width of object, begin - current value
        CMPB MAX_OBJECT_WIDTH ; check to see if object width is the widest
        BLS CFO_COL_LOOP ; not widest object, go back to find objects

CFO_COL_NEW_WIDEST_OBJECT:
        STAB MAX_OBJECT_WIDTH ; save the new max object width
        LSRB ; divide object width by 2
        LDAA COL_INDEX ; col index + half width = center point
        SBA
        STAA COL_OBJECT_CENTER ; store center value. now we have center and
width for the max point
        BRA CFO_COL_LOOP ; back to beginning of find objects to continue loop

CFO_COL_END_FIND_OBJECTS:
        LDAB OBJECT_EXIST ; load the value to see if you are currently in an
object(off the side of the pic)
```

```
        BEQ CFO_COL_CALCS ; if zero, no object, not in object, do nothing. aim
motor and move on to rows.

CFO_COL_LAST_OBJECT_END:
        LDAB COL_INDEX
        SUBB END_OF_OBJECT ; load the end(beginning) of object
        CMPB MAX_OBJECT_WIDTH ; check to see if object width is the widest,
width is just start since the
                                ;end is 0
        BLS CFO_COL_CALCS ; not widest object, aim motor and move on to rows

CFO_COL_NEW_WIDEST_OBJECT2:
        STAB MAX_OBJECT_WIDTH ; save the new max object width
        LSRB ; divide object width by 2
        LDAA COL_INDEX  ; subtract the width from the current index to get the
center
        SBA
        STAA COL_OBJECT_CENTER ; store center value, which is width/2 since
start is 0. now have center and width for the max point

CFO_COL_CALCS:
      LDAA MAX_OBJECT_WIDTH ; load max object width
      CMPA #MINCOLWIDTH ; check to see if it's above the min for motion
      BHS CFO_COL_CALCS2 ; above cutoff, aim motor
      LDAA #$27 ; load index of lcd message
      JSR lcd_topmsg ; "REALIGN ", "CAL IMG"
      LDAA #$28 ; load index of lcd message
      JSR lcd_bottommsg ; "REALIGN ", "CAL IMG"
      LDX #COL_DATA_ADDR_END ; load the address of the end of column data
COL_ZERO_DATA2:
      MOVB #$00, 1,X- ; move 0 into the col data addr, then post dec x
      CPX #COL_DATA_ADDR_START ; compare current addr to start
      BHS COL_ZERO_DATA2 ; if >= go to next col value, else continue to rows
      RTS ; exit find center, no motion
CFO_COL_CALCS2:
        LDAA COL_INDEX ; load col index to check value
        CMPA #COLS13 ; check for area 1
        BEQ CFO_COL_OBJ1_CALCS ; area 1 calcs
        CMPA #COLS23 ; check to see if you are in the middle
        BEQ CFO_COL_OBJ2_CALCS ; area 2 calcs
        MOVB COL_OBJECT_CENTER, COL_OBJ3 ; value for object3 stored
        LBRA COL_ZERO_DATA ; obj 3 is last one, done with checks, move to rows
CFO_COL_OBJ1_CALCS:
        MOVB COL_OBJECT_CENTER, COL_OBJ1 ; value for object1 stored
        LBRA CFO_COL_BEGIN ; done with obj1, move on to check obj2
CFO_COL_OBJ2_CALCS:
        MOVB COL_OBJECT_CENTER, COL_OBJ2 ; value for object2 stored
        LBRA CFO_COL_BEGIN ; done with obj2, move on to check obj3

COL_FIND_OBJECTS:
        DEC COL_INDEX ; decrement column index to show correct column
        BEQ COL_END_FIND_OBJECTS; if col index is 0, all columns have been
checked, branch past find objects
        LDAA MAXCOLV ; load the cutoff threshhold into the A register
        CMPA 1,-X ; check to see if it is an object (above threshhold)
        BHI COL_BELOW_THRESHHOLD ; if maxcol > current value, no object
```

```
COL_OBJECT_FOUND:
        LDAB OBJECT_EXIST ; load the value to see if you are currently in an
object
        BNE COL_FIND_OBJECTS; if non zero, object already existed, do nothing

COL_NEW_OBJECT:
        MOVB #$01,OBJECT_EXIST ; object just started, set object_exists = 1
        MOVB COL_INDEX,END_OF_OBJECT ; store col_index as the end(beginning) of
a new object
        BRA COL_FIND_OBJECTS ; back to find objects loop

COL_BELOW_THRESHHOLD:
        LDAB OBJECT_EXIST ; load the value to see if you are currently in an
object
        BEQ COL_FIND_OBJECTS ; if zero, no object, not in object, do nothing.
return to find objects for
                              ; next col

COL_OBJECT_END:
      MOVB #$00,OBJECT_EXIST  ; no longer in an object
        LDAB END_OF_OBJECT ; load the end(beginning) of object
        SUBB COL_INDEX ; find width of object, begin - current value
        CMPB MAX_OBJECT_WIDTH ; check to see if object width is the widest
        BLS COL_FIND_OBJECTS ; not widest object, go back to find objects

COL_NEW_WIDEST_OBJECT:
        STAB MAX_OBJECT_WIDTH ; save the new max object width
        LSRB ; divide object width by 2
        ADDB COL_INDEX ; col index + half width = center point
        STAB COL_OBJECT_CENTER ; store center value. now we have center and
width for the max point
        BRA COL_FIND_OBJECTS ; back to beginning of find objects to continue
loop

COL_END_FIND_OBJECTS:
        LDAB OBJECT_EXIST ; load the value to see if you are currently in an
object (off the side of the
                            ;image)
        BEQ CHECK_COL_OBJECT_WIDTH ; if zero, no object, not in object, do
nothing. aim motor and move on to
                                    ;rows. else, check stuff below

COL_LAST_OBJECT_END:
        LDAB END_OF_OBJECT ; load the end(beginning) of object
        CMPB MAX_OBJECT_WIDTH ; check to see if object width is the widest,
width is just start since the
                                ;end is 0
        BLS CHECK_COL_OBJECT_WIDTH ; not widest object, aim motor and move on
to rows

COL_NEW_WIDEST_OBJECT2:
        STAB MAX_OBJECT_WIDTH ; save the new max object width
        LSRB ; divide object width by 2
        STAB COL_OBJECT_CENTER ; store center value, which is width/2 since
start is 0. now have center and
                                 ;width for the max point
```

```
CHECK_COL_OBJECT_WIDTH:
      LDAA MAX_OBJECT_WIDTH ; load max object width
      CMPA #MINCOLWIDTH ; check to see if it's above the min for motion
      BHS AIM_PAN_MOTOR ; above cutoff, aim motor
      MOVB #$00, MOTION_DETECTED ; no motion, object not wide enough, go to end
      LBRA END_FIND_OBJECTS ; exit find center, no motion

AIM_PAN_MOTOR:
      LDAB #$B0         ; image stored upside down, flip col value when aiming
      SUBB COL_OBJECT_CENTER ; load the center value col index
      LDAA #$00
      LDY COL_SLOPE_AVG ; load the slope multiplier for col aiming
      EMUL ; multiply! stored in D
      LSRD        ; divide by 16 ($10) to cancel out the slope multiplier
      LSRD             ; used to reduce rounding errors with remainders
      LSRD
      LSRD
      STD TEMP_PRODUCT ; store the multiply since you can't sub two 16 bit
registers
      LDD COL_AIM_OFFSET ; load the offset, then sub the product. for aiming
cols, pwm period goes right to
                           ;left, sub not add
      SUBD TEMP_PRODUCT ; subs the product from the offset, now you have y =
mx+b (b-mx really) and you're
                          ;ready to aim
      STD TC3 ; store the 2 byte value for the pwm duty cycle to aim the pan
motor, then move onto rows

      LDX #COL_DATA_ADDR_END ; load the address of the end of column data
COL_ZERO_DATA:
      MOVB #$00, 1,X- ; move 0 into the col data addr, then post dec x

      CPX #COL_DATA_ADDR_START ; compare current addr to start
      BHS COL_ZERO_DATA ; if >= go to next col value, else continue to rows

ROW_BEGIN_FIND_CENTER:
      LDX #ROW_DATA_ADDR_END ; load the address of the end of row data
      MOVB ROW_DATA_ADDR_END, MAXROWV ; store first(last) row value as
maxrowvalue

ROW_FIND_MAX:
      CPX #ROW_DATA_ADDR_START ; check to see if you are at the beginning of
the row data
      BLS CHECK_MAXROWV_THRESHHOLD ; if still >, keep checking values, else go
to find object
      LDAA MAXROWV ; load the max row value into the A register
      SUBA 1,X- ; do the subtraction and post dec X
      BHI ROW_FIND_MAX ; if not a new max, branch back to the check loop
      MOVB 1,X,MAXROWV ; move the new max into maxrowv
      BRA ROW_FIND_MAX ; next row

CHECK_MAXROWV_THRESHHOLD:
      LDAA MAXROWV ; load maxcolv
      CMPA #MAXROWV_THRESHHOLD ; check to see if maxcolv is high enough for
motion
      BHI ROW_BEGIN_FIND_OBJECTS ; above threshold, motion detected
      MOVB #$00, MOTION_DETECTED ; no motion, store 0
```

```
      LBRA END_FIND_OBJECTS ; no motion, finish sub

ROW_BEGIN_FIND_OBJECTS:
      LDX #ROW_DATA_ADDR_END ; load the address of the end of row data
      ; maxrowv already in A register
      LSRA ; divide max row value by 2, this threshhold is used for finding
important rows
      STAA MAXROWV ; store this new value in maxrowv since we dont care about
maxrowv anymore
      MOVB #$00,OBJECT_EXIST ; initialize object exist to 0, means not
currently in object
      MOVB NUM_OF_ROWS,END_OF_OBJECT ; initialize end of object as the last row
      MOVB NUM_OF_ROWS,ROW_INDEX ; keeps track of current row index
      INC ROW_INDEX ; inc once because it decs at beginning of find object
      MOVB #$00,MAX_OBJECT_WIDTH ; widest object is 0 by default

CHECK_ROW_CAL_REF_IMG:
      LDAA CAL_REF_IMG ; check to see if its a cal ref img or real image
      LBEQ ROW_FIND_OBJECTS ; if 0, normal image, else special image
      LDX #ROW_DATA_ADDR_START ; load in addr of first col data
      MOVB #$00, ROW_INDEX ; start at col 0
      MOVB #$00, MOTION_DETECTED ; no timestamps in cal ref check

CFO_ROW_BEGIN:
      MOVB #$00, OBJECT_EXIST ; object doesn't exist to begin with
      MOVB #$00, MAX_OBJECT_WIDTH ; reset widest object to 0

CFO_ROW_LOOP:
      INC ROW_INDEX ; inc row index variable to keep track, starts at 0
      LDAA ROW_INDEX ; load row index
      CMPA #ROWS13 ; check to see if you are on left
      BEQ CFO_ROW_END_FIND_OBJECTS ; end area 1
      CMPA #ROWS23 ; check to see if you are in the middle
      BEQ CFO_ROW_END_FIND_OBJECTS ; end area 2
      CMPA #NUM_OF_ROWS ; check to see if you are on right
      BEQ CFO_ROW_END_FIND_OBJECTS ; end area 3

      LDAA #CAL_THOLD ; load the cutoff threshhold into the A register
      CMPA 1,X+ ; check to see if it is an object (above threshhold), post inc
x
      BHI CFO_ROW_BELOW_THRESHHOLD ; if maxcol > current value, no object

CFO_ROW_OBJECT_FOUND:
      LDAB OBJECT_EXIST ; load the value to see if you are currently in an
object
      BNE CFO_ROW_LOOP; if non zero, object already existed, do nothing

CFO_ROW_NEW_OBJECT:
      MOVB #$01,OBJECT_EXIST ; object just started, set object_exists = 1
      MOVB ROW_INDEX,END_OF_OBJECT ; store col_index as the end(beginning) of a
new object
      BRA CFO_ROW_LOOP ; back to find objects loop

CFO_ROW_BELOW_THRESHHOLD:
      LDAB OBJECT_EXIST ; load the value to see if you are currently in an
object
```

```
      BEQ CFO_ROW_LOOP ; if zero, no object, not in object, do nothing. return
to find objects for next col

CFO_ROW_OBJECT_END:
      MOVB #$00,OBJECT_EXIST
      LDAB ROW_INDEX ; load the end(beginning) of object
      SUBB END_OF_OBJECT ; find width of object, begin - current value
      CMPB MAX_OBJECT_WIDTH ; check to see if object width is the widest
      BLS CFO_ROW_LOOP ; not widest object, go back to find objects

CFO_ROW_NEW_WIDEST_OBJECT:
      STAB MAX_OBJECT_WIDTH ; save the new max object width
      LSRB ; divide object width by 2
      LDAA ROW_INDEX ; col index + half width = center point
      SBA
      STAA ROW_OBJECT_CENTER ; store center value. now we have center and width
for the max point
      BRA CFO_ROW_LOOP ; back to beginning of find objects to continue loop


CFO_ROW_END_FIND_OBJECTS:
      LDAB OBJECT_EXIST ; load the value to see if you are currently in an
object (off the side of the ;
                        ;image)
      BEQ CFO_ROW_CALCS ; if zero, no object, not in object, do nothing. aim
motor and move on to rows.
                        ;else, check stuff below

CFO_ROW_LAST_OBJECT_END:
      LDAB ROW_INDEX
      SUBB END_OF_OBJECT ; load the end(beginning) of object
      CMPB MAX_OBJECT_WIDTH ; check to see if object width is the widest, width
is just start since the end
                            ;is 0
      BLS CFO_ROW_CALCS ; not widest object, aim motor and move on to rows

CFO_ROW_NEW_WIDEST_OBJECT2:
      STAB MAX_OBJECT_WIDTH ; save the new max object width
      LSRB ; divide object width by 2
      LDAA ROW_INDEX     ; find the new center
      SBA
      STAA ROW_OBJECT_CENTER ; store center value, which is width/2 since start
is 0. now have center and
                             ;width for the max point

CFO_ROW_CALCS:
      LDAA MAX_OBJECT_WIDTH ; load max object width
      CMPA #MINROWHEIGHT ; check to see if it's above the min for motion
      BHS CFO_ROW_CALCS2 ; above cutoff, aim motor
      LDAA #$27 ; load index of lcd message
      JSR lcd_topmsg ; "REALIGN ", "CAL IMG""
      LDAA #$28 ; load index of lcd message
      JSR lcd_bottommsg ; "REALIGN ", "CAL IMG"
      RTS ; exit find center, no motion
CFO_ROW_CALCS2:
      LDAA ROW_INDEX ; load col index to check value
      CMPA #ROWS13 ; check for area 1
```

```
      BEQ CFO_ROW_OBJ1_CALCS ; area 1 calcs
      CMPA #ROWS23 ; check to see if you are in the middle
      BEQ CFO_ROW_OBJ2_CALCS ; area 2 calcs
      MOVB ROW_OBJECT_CENTER, ROW_OBJ3 ; value for object3 stored
      MOVB #$00, CAL_REF_IMG ; set calrefobj to 0 indicating to the cal loop
that the image is done
      RTS; obj 3 is last one, done with checks, no timestamp in cal, return
from sub
CFO_ROW_OBJ1_CALCS:
      MOVB ROW_OBJECT_CENTER, ROW_OBJ1 ; value for object1 stored
      LBRA CFO_ROW_BEGIN ; done with obj1, move on to check obj2
CFO_ROW_OBJ2_CALCS:
      MOVB ROW_OBJECT_CENTER, ROW_OBJ2 ; value for object2 stored
      LBRA CFO_ROW_BEGIN ; done with obj2, move on to check obj3

ROW_FIND_OBJECTS:
      DEC ROW_INDEX ; decrement row index to show correct row
      BEQ ROW_END_FIND_OBJECTS; if row index is 0, all rows have been checked,
branch past find objects
      LDAA MAXROWV ; load the cutoff threshhold into the A register
      CMPA 1,-X ; check to see if it is an object (above threshhold)
      BHI ROW_BELOW_THRESHHOLD ; if maxrow > current value, no object

ROW_OBJECT_FOUND:
      LDAB OBJECT_EXIST ; load the value to see if you are currently in an
object
      BNE ROW_FIND_OBJECTS; if non zero, object already existed, do nothing

ROW_NEW_OBJECT:
      MOVB #$01, OBJECT_EXIST ; object just started, set object_exists = 1
      MOVB ROW_INDEX,END_OF_OBJECT ; store row_index as the end(beginning) of a
new object
      BRA ROW_FIND_OBJECTS ; back to find objects loop

ROW_BELOW_THRESHHOLD:
      LDAB OBJECT_EXIST ; load the value to see if you are currently in an
object
      BEQ ROW_FIND_OBJECTS ; if zero, no object, not in object, do nothing.
return to find objects for next
                           ;row

ROW_OBJECT_END:
      MOVB #$00, OBJECT_EXIST
      LDAB END_OF_OBJECT ; load the end(beginning) of object
      SUBB ROW_INDEX ; find width of object, begin - current value
      CMPB MAX_OBJECT_WIDTH ; check to see if object width is the widest
      BLS ROW_FIND_OBJECTS ; not widest object, go back to find objects

ROW_NEW_WIDEST_OBJECT:
      STAB MAX_OBJECT_WIDTH ; save the new max object width
      LSRB ; divide object width by 2
      ADDB ROW_INDEX ; row index + half width = center point
      STAB ROW_OBJECT_CENTER ; store center value. now we have center and width
for the max point
      BRA ROW_FIND_OBJECTS ; back to beginning of find objects to continue loop

ROW_END_FIND_OBJECTS:
```

```
      LDAB OBJECT_EXIST ; load the value to see if you are currently in an
object (off the side of the
                        ;image)
      BEQ CHECK_ROW_OBJECT_HEIGHT ; if zero, no object, not in object, do
nothing. move on to aiming
                                  ;motors. else, check stuff below

ROW_LAST_OBJECT_END:
      LDAB END_OF_OBJECT ; load the end(beginning) of object
      CMPB MAX_OBJECT_WIDTH ; check to see if object width is the widest, width
is just start since the end
                           ;is 0
      BLS CHECK_ROW_OBJECT_HEIGHT ; not widest object, move on to aiming motors

ROW_NEW_WIDEST_OBJECT2:
      STAB MAX_OBJECT_WIDTH ; save the new max object width
      LSRB ; divide object width by 2
      STAB ROW_OBJECT_CENTER ; store center value, which is width/2 since start
is 0. now have center and
                             ;width for the max point

CHECK_ROW_OBJECT_HEIGHT:
      LDAA MAX_OBJECT_WIDTH ; load max object width
      CMPA #MINROWHEIGHT ; check to see if it's above the min for motion
      BHS AIM_TILT_MOTOR ; above cutoff, aim motor
      MOVB #$00, MOTION_DETECTED ; no motion, object not wide enough, go to end
      BRA END_FIND_OBJECTS ; exit find center, no motion

AIM_TILT_MOTOR:
      BSET PTH, #$04 ; turn on laser pointer
      LDAB #$48  ; image data stored backwards, flip row value when aiming
      SUBB ROW_OBJECT_CENTER ; load the center value row index
      LDAA #$00
      LDY ROW_SLOPE_AVG ; load the slope multiplier for row aiming
      EMUL ; multiply! stored in D
      LSRD         ; divide by 16 ($10) to cancel out the slope multiplier
      LSRD         ; used to reduce rounding errors with remainders
      LSRD
      LSRD
      ADDD ROW_AIM_OFFSET ; adds the offset to the slope*center, now you have y
= mx+b and you're ready to aim row
      jsr   lcd_polldelay
      jsr   lcd_polldelay
      STD TC5 ; store the 2 byte value for the pwm duty cycle to aim the tilt
motor

END_FIND_OBJECTS:
      LDAA MOTION_DETECTED          ; check for motion
      BNE MOVEMENT_DETECTED         ; branch if yes motion, stay if not
      BCLR PTH, #$04                ; no motion, turn off laser pointer
      MOVB #$00, REF_FRAME_COUNTER2 ; reset motion ref frame counter
      INC REF_FRAME_COUNTER1          ; inc no motion ref frame counter
      LDAA REF_FRAME_COUNTER1         ; check no motion ref frame counter
      CMPA #$10                       ; if no motion detected $10 frames in a
row
      BLS END_FC                              ; get new reference image
      MOVB #$01,REFIMG                ; this tells uC to save new ref image
```

```
      MOVB #$00, REF_FRAME_COUNTER1 ; new ref saved, reset ref counter

END_FC:
      RTS                                   ; no motion, no timestamp. end
find center

MOVEMENT_DETECTED:
               LDAA MOTION_DETECTED    ; motion detected, check how long
               CMPA #$60                     ; if motion detected for $60
frames, get new ref frame
               BLO timestamp_record    ; less than 60, just take a timestamp
               MOVB #$01, REFIMG             ; tell uC to get new ref img
               MOVB #$00, MOTION_DETECTED ; reset motion detected

timestamp_record:

              cmpa     #$01                    ; motion detected already in the
A register, compare to 1
              lbhi  ts_skipincnum      ; higher than 1, timestamp already
taken, 1 take new timestamp
                                       ; 0 means no motion and this function
should never be called
            ts_updateclk
            ldx    ts_pointer               ;find where we are in the buffer
            movb   rtc_temphr,0,x    ;write in the current hours
            inx
            movb   rtc_tempmin,0,x  ;write in the current minutes
            inx
            movb   rtc_tempsec,0,x  ;write in the current seconds
            inx
            stx    ts_pointer               ;store the new value of ts_pointer
            cpx    #ts_endbuffer     ;compare it to the upper bound of the
buffer
            bne    tsr_skipreset    ;if it is equal to the end of the buffer
            movw   #ts_buffer,ts_pointer  ;reset it
            ldx    ts_pointer
tsr_skipreset:                              ;otherwise
            ldaa  ts_numstamps               ;load the current number of
timestamps
            cmpa  #$0A                              ;if there's 10, don't
increment
            beq   ts_skipincnum
            inca                                      ;otherwise increment
            staa  ts_numstamps               ;and store
ts_skipincnum:
                                              ; no timestamp needed if sent
here



      RTS ; done!


;***********************************************************
;LCD Library
;***********************************************************
;Data comes out on PORTA
```

```
;E comes out on PTS(0)
;RS comes out on PTS(6)
;RW comes out on PTS(5)

;This loop is designed so button polling isn't free running
lcd_polldelay:
       pshd
       pshx
         pshy
         ldy #$FFFF
t_inpollwait:
      idivs
      dey
      cpy   #$0000
      bne   t_inpollwait
      puly
      pulx
      puld
      rts

lcd_polldelay2:
       pshd
       pshx
         pshy
         ldy #$FFFF
t_inpollwait2:
      idivs
      idivs
      idivs
      dey
      cpy   #$0000
      bne   t_inpollwait2
      puly
      pulx
      puld
      rts

;Have the data to write on register A and write it to the LCD.
;Waits for the appropriate amount of time.
lcd_write:
      pshd
      pshx
      staa  PORTA                   ;Set data to send on PORTA
      bset  PTS,#%00000001    ;Pulse Eclk, outputting the character
      nop
      nop
      bclr  PTS,#%00000001
      pshy
      ldy #$600
inwaitloop2:
      idivs
      dey
      cpy   #$0000
      bne   inwaitloop2
      puly
      pulx
      puld
```

```
      rts

med_lcd_write:
      pshd
      pshx
      staa  PORTA                   ;Set data to send on PORTA
      bset  PTS,#%00000001    ;Pulse Eclk, outputting the character
      nop
      nop
      bclr  PTS,#%00000001
      pshy
      ldy #$FFFF
inwaitloop7:
      idivs
      dey
      cpy   #$0000
      bne   inwaitloop7
      puly
      pulx
      puld
      rts

long_lcd_write:
      pshd
      pshx
      staa  PORTA                   ;Set data to send on PORTA
      bset  PTS,#%00000001    ;Pulse Eclk, outputting the character
      nop
      nop
      bclr  PTS,#%00000001
      pshy
      ldy #$FFFF
long_inwaitloop2:
      idivs
      idivs
      idivs
      dey
      cpy   #$0000
      bne   long_inwaitloop2
      puly
      pulx
      puld
      rts


;This function sets the LCD control signals to read in from the LCD
lcd_readmode:
      movb  #$60,PTS          ;Set R/W to 1 and RS to 1
      rts




;This function outputs one of the predefined messages in flash
;The message number to use is stored in the A register on passing
;This one outputs to the top line
lcd_topmsg:
```

```
            pshb
            pshx
            psha
            ldab    #$0C
            lcd_settingmode
            ldaa    #$02
            jsr     lcd_write           ;Go to the home position on the LCD
            pula
            ldx     #$4000
lcd_ltt_mvptr                               ;LCD lookup table top move
pointer
            cmpa    #$00
            beq     lcd_ptr_ready_top
           abx
           deca
           bra     lcd_ltt_mvptr
lcd_ptr_ready_top
           decb
           lcd_writemode
            ldaa    1,x+
           jsr     lcd_write
           cmpb    #$00
           bne     lcd_ptr_ready_top

            pulx
            pulb
               rts


;This one outputs to the bottom line
lcd_bottommsg:
            pshb
            pshx
            psha
            ldab    #$0C
            lcd_settingmode
            ldaa    #$A8
            jsr     lcd_write           ;Go to the home position on the LCD
            pula
            ldx     #$4000
lcd_ltb_mvptr                               ;LCD lookup table move pointer
            cmpa    #$00
            beq     lcd_ptr_ready_bot
           abx
           deca
           bra     lcd_ltb_mvptr
lcd_ptr_ready_bot
           decb
           lcd_writemode
            ldaa    1,x+
           jsr     lcd_write
           cmpb    #$00
           bne     lcd_ptr_ready_bot

            pulx
            pulb
             rts
```

```
;This function returns the LCD cursor to the home position
lcd_cursorhome:
            psha
            ldaa  #$02
            lcd_settingmode
            jsr   lcd_write
            lcd_writemode
            pula
            rts

lcd_clrscreen:
            psha
            ldaa  #$01
            lcd_settingmode
            jsr   lcd_write
            lcd_writemode
            pula
            rts

lcd_output2digits:

            pshx
            psha
            pshb
            clra                    ;Clear the A register for later IDIV
instructions
            ldx   #$000A            ;Get the upper digit
            idiv
            tfr   x,d
            addb  #$30

            tfr   b,a               ;Move the value in port B to port A
            jsr   lcd_write         ;Write the character to the LCD

            clra
            pulb
            ldx   #$000A
            idiv
            addb  #$30

            tfr   b,a
            jsr   lcd_write         ;Write the lower digit to the LCD
             pula
             pulx
            rts

;*************************************************************
;ATD
;*************************************************************

atd_init:

;REGISTER ATDCTL2: Val = 0xC0: TURNS ON ATD
            movb  #$C0,ATD1CTL2
;REGISTER ATDCTL4: VAL = 0x00: SETS 10 BIT RESOLUTION
            movb  #$00,ATD1CTL4
```

```
;REGISTER ATDCTL5: VAL = 0xA7: SELECTS INPUT CHANNEL,SCAN MODE
            movb  #$A7,ATD1CTL5
;USE REGISTER ATDDR0H TO READ IN RESULT

;REGISTER ATDCTL2: Val = 0xC0: TURNS ON ATD
            movb  #$C0,ATD0CTL2
;REGISTER ATDCTL4: VAL = 0x00: SETS 10 BIT RESOLUTION
            movb  #$00,ATD0CTL4
;REGISTER ATDCTL5: VAL = 0xA7: SELECTS INPUT CHANNEL,SCAN MODE
            movb  #$A7,ATD0CTL5
;USE REGISTER ATDDR0H TO READ IN RESULT



        rts

atd_turnoff:
        movb    #$00,ATD0CTL2 ;Turns off ATD0
        movb    #$00,ATD1CTL2 ;Turns off ATD1
        rts


;*************************************************************
;Real time clock interrupt
;*************************************************************
isr_paboverflow:
            ldaa  rtc_decisecs
            ldab  #$04
            aba
            staa  rtc_decisecs
            ldaa  rtc_seconds
            ldab  #$28 ;41 decimal
            aba
            staa  rtc_seconds
            ldaa  rtc_minutes
            ldab  #$2B ;43 decimal
            aba
            staa  rtc_minutes

                   ldaa   rtc_decisecs
                   cmpa   #$0A
                   blt    ts_skipincsecs1
                   inc    rtc_seconds
                   suba   #$0A
                   staa   rtc_seconds
ts_skipincsecs1
                   ldaa   rtc_seconds
                   cmpa   #$3C
                   blt    ts_skipincmins1
                   inc    rtc_minutes
                   suba   #$3C
                   staa   rtc_seconds

ts_skipincmins1

                   ldaa   rtc_minutes
                   cmpa   #$3C
```

```
                  blt    ts_skipinchrs1
                  inc    rtc_hours
                  suba   #$3C
                  staa   rtc_minutes

ts_skipinchrs1    ldaa          rtc_hours
                  cmpa          #$18                ;24 hex
                  blt          ts_skiphrreset1
                  movb          #$00,rtc_hours

ts_skiphrreset1

            bset  PAFLG,#%00000010
            cli
            rti

;*************************************************************
;*                  Interrupt Vectors                        *
;*************************************************************

  org $FFDC
  fdb     isr_paboverflow
  ORG $FFCC
  fdb     isr_href            ;Port H
  fdb     isr_pclkvsync       ;Port J
  ORG $FFFE

  fdb     Entry      ; Reset
```

Appendix G: FMECA Worksheet

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
A1	Output = 0V	Failure of any component within functional block A or an external short	None of the circuit components will function (system will be 'off')	Observation	High	Voltage Regulator set to trip at current over 600mA
A2	Output > 5V	Failure of U3 or V1	Potential damage to microcontroller, camera, LCD, or related components, unpredictable behavior	Observation	High	Voltage Regulator set to trip at current over 600mA
A3	Output out of Tolerance	C10, C11, C12, C13, C14, D1, L1, U3	High ripple or out-of-spec operating voltage, unpredictable effects	Observation	High	Ripple could potentially destroy components, resulting in injury
B1	Output Stuck High/Low	Failure of any component within function block B	Depending on pin, I2C failure, camera communication failure, LCD communication failure, servo failure	Observation	Low/High	Criticality high if system is being used in a potentially harmful way
C1	Faulty Image Transmitted	Camera Module, Software, I2C failure	Failure to detect/follow motion, seemingly random servo movements	Observation	Low/High	Criticality high if system is being used in a potentially harmful way
C2	Image Sensor Fails to Respond	Camera Module, Software, I2C failure	Failure to acquire any image data	Observation	Low	Microcontroller could detect, but not correct, this failure
D1	Blank LCD / Failure to Initialize	R3, C9, Software, port pin stuck high or low	Loss of method to display information to user	Observation	Low	
D2	"Random" or Incorrect LCD Output	C9, Software, port pin stuck high or low	Loss of method to display information to user	Observation	Low	
E1	Potentiometers Have No Effect During Calibration	R1, R2, U1, Software	Loss of method of calibration	Observation	Low/High	Criticality high if system is being used in a potentially harmful way

FEMCA Worksheet (continued)

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
E2	Jerky or Inconsistent Calibration Movements	R1, R2, U1, Software, Servo Motors	Difficulty calibrating, possible loss of calibration method	Observation	Low/High	Criticality high if system is being used in a potentially harmful way
F1	Laser Does Not Move	Port pin stuck high or low, Software, Servo Motors, Image Sensor	Loss of method of targeting	Observation	Low/High	Criticality high if system is being used in a potentially harmful way
F2	Laser Does Not Follow Target Properly	Software, Servo Motors, Image Sensor	Loss of method of targeting	Observation	Low/High	Criticality high if system is being used in a potentially harmful way
F3	Servo extends to rotation limit	Software, Servo Motors, U1, Power supply failure	Excessive power consumption, temporary loss of targeting	Observation	Low/High	Microcontroller should not allow PWM cycle to exceed bounds
G1	Button Irresponsive	SW1, SW2, SW5, R4, R5, R6, U1, Software	Loss of user interface, calibration	Observation	Low	Criticality low because system never gets out of startup mode
G2	Laser Pointer Never On	SW5, port pin stuck low, R6	Loss of laser pointer use	Observation	Low	
G3	Laser Pointer Always On	SW5, port pin stuck high	Additional power consumption, laser remains on	Observation	High	Microcontroller could detect stuck port pin and turn off system